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RESEARCH ARTICLE

Associations between microplastic pollution and land use in urban wetland sediments

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Abstract
Microplastic pollution is concerning because it is widespread in aquatic environments and there is growing evidence of negative biological effects. Here, we present one of the first studies to examine microplastic pollution (plastic particles < 1 mm) in urban wetlands and investigate relationships between contamination and urban land use. Sediment samples were collected from 20 independent urban wetlands, each with different types of urban land use within their catchments. Microplastics were observed at all wetlands, with an average abundance of around 46 items/kg of dry sediment. Plastic fragments were the most common type of microplastic, accounting for 68.5% of all microplastics found. Consistent with other studies, microplastic abundance was positively correlated with increased catchment urbanisation. On closer examination, plastic fragments and beads correlated with catchment urbanisation. Fragment abundance also increased in wetlands with catchments that had a higher proportion of industrial land use and decreased in catchments with higher residential densities. This study demonstrates the susceptibility of urban wetlands to microplastic pollution, further highlighting the ubiquitous nature of microplastic pollution. The prevalence of microplastic fragments indicates that plastic litter degradation is a significant source of microplastics in urban environments, especially in industrial areas.

Keywords Microplastic · Pollution · Freshwater · Wetland · Sediment · Urbanisation · Land use

Introduction

Plastic products are used everywhere. Their versatility in a range of applications and low production price has seen plastic production increase to 311 million tonnes (MT) in 2014 (PlasticsEurope 2015). In 2010, an estimated 275 MT of plastic was produced, while 4.8 to 12.7 MT ultimately ended up in the ocean (Jambeck et al. 2015). With such large quantities entering the ocean and very long degradation times, plastic pollution is one of the most serious anthropogenic problems affecting aquatic ecosystems (Avio et al. 2017).

Microplastics were recently identified as a new class of pollutant and an emerging threat to aquatic ecosystems (Avio et al. 2017; Sharma and Chatterjee 2017). They have been observed in many aquatic ecosystems around the world (e.g. Cole et al. 2011; Eerkes-Medrano et al. 2015; Hidalgo-Ruz and Thiel 2013; Van Cauwenberghe et al. 2015; Wagner et al. 2014), and there is a growing body of literature showing that they can adversely affect biota. Microplastic ingestion by organisms has been reported in both field and laboratory studies (e.g. Brennecke et al. 2015; Van Cauwenberghe and Janssen 2014; Chua et al. 2014). Some effects of microplastics include physically damaging organisms, translocating and/or bioaccumulating in different tissues, inducing inflammatory responses and decreasing metabolism (Browne et al. 2008; Rochman et al. 2014; von Moos et al. 2012). Microplastics also absorb toxic compounds, such as persistent organic pollutants (POPs) (Chua et al. 2014) and metals (Teuten et al.

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2009), with organisms potentially exposed to these compounds when they are ingested.

Most research on microplastics has focussed on marine and estuarine ecosystems. However, in the last 5 years, attention has shifted to microplastic pollution in freshwater environments, notably rivers (e.g. Castaneda et al. 2014; Lechner et al. 2014; McCormick et al. 2014) and lakes (e.g. Eriksen et al. 2013; Fischer et al. 2016; Free et al. 2014). Little information exists regarding microplastic pollution in urban wetlands.

Urban wetlands provide essential services for surrounding populations, such as stormwater management (flood control), aesthetic values and recreational values. They also provide essential ecosystem services, including reducing nutrients and other pollutant loads in stormwater before it enters receiving waters, as well as creating valuable habitat for wildlife in an otherwise hostile urban landscape (Hamer and Parris 2011; Moore and Hunt 2012). Unfortunately, their role in stormwater management can conflict with the ecological values they provide. Urban wetlands can become 'sinks' for many of the pollutants carried in stormwater runoff, which accumulate in wetlands and reach hazardous concentrations over time (Marshall et al. 2016; Sharley et al. 2017).

Monitoring pollution in wetland sediments can provide useful information about stressors to local biota and provide important information about the types of pollutants being generated by urban activities, as well as where pollutants are being generated. Many of the compounds polluting urban wetlands have been well characterised, with the types and magnitude of pollution strongly linked to development intensity and urban land use types (Marshall et al. 2016; Sharley et al. 2017). This is not the case for microplastic pollution. The aim of the current study was to investigate the occurrence of microplastic pollution in urban wetland sediments and determine if there were relationships between microplastic pollution and urban land use type.

Materials and methods

Study area

Sediment samples were collected from 20 urban wetlands in the Greater Melbourne Region, Victoria, Australia (Fig. 1). These wetlands were a mixture of natural and constructed wetlands and were selected because each wetland was situated in independent catchments that differed in the types and proportion of urban land uses within that catchment. The wetlands predominantly receive water from stormwater runoff, which would also include pollutants associated with stormwater in their respective catchments. Descriptions of catchment size and land use determination are given in Marshall et al. (2016) and Sharley et al. (2017). Briefly, catchments were determined from primary 10-m flow-weighted digital elevation models in ArcGIS 10.3. The spatial analyst extension, the digital elevation models were derived using TOPOGRID from LiDAR 5-m contours. Catchments were then calculated from flow and accumulation layers. Catchment boundaries were adjusted to conform to higher-resolution watershed layers and align with stormwater drains. Comparisons were made with streams, drains and watersheds derived for sediment ponds that are managed by the regional water authority as a form of quality control. Catchment land use was calculated from mesh block counts in the 2011 Australian population census (Australian Bureau of Statistics 2011). Land uses were commerce, industrial, open space (undeveloped), residential, road/rail, rural, semi-rural and urban growth, while population data were population density (persons/hectare) and dwelling density (dwellings/hectare). Detailed land use and population data for each wetland catchment are provided in the Supplementary Data.

Sediment collection

To get a sample representative of microplastic contamination at each wetland, sediment was collected from three locations in the wetland: the inlet (where stormwater enters the wetland), middle and outlet (where water leaves the wetland into a receiving body such as a river). At each location, a single sample of 500 mL of surficial sediments (< 2 cm deep) was collected using a shovel. Care was taken to ensure sediment was not washed away during collection. Sediments from each location were then combined into a composite sample, of which 500 mL was then processed for microplastics. All samples were stored in sealed glass jars and stored at 4 °C prior to processing.

Sample processing

A density separation method was used to extract microplastics from the sediment. Currently, there is no consensus on upper size limit of microplastics, with most studies defining microplastics as plastic particles < 5 mm or < 1 mm; we adopted the < 1-mm definition. Many studies recommend the use of a sodium chloride (NaCl) solution for extracting microplastics, though there are concerns that heavier types of plastics will not be extracted from the sediment. An alternative is to use zinc chloride ($ZnCl_2$) solution, which is denser but is costlier and has the potential to cause environmental damage.

Microplastic removal efficiency of $ZnCl_2$ was compared with NaCl density separation technique by spiking clean, artificial sediment (a sand, kaolin clay and peat mixture) with a known number of plastic fragments with different densities. The plastic fragments were derived from larger plastic products and included polypropylene, polyethylene, acrylic,

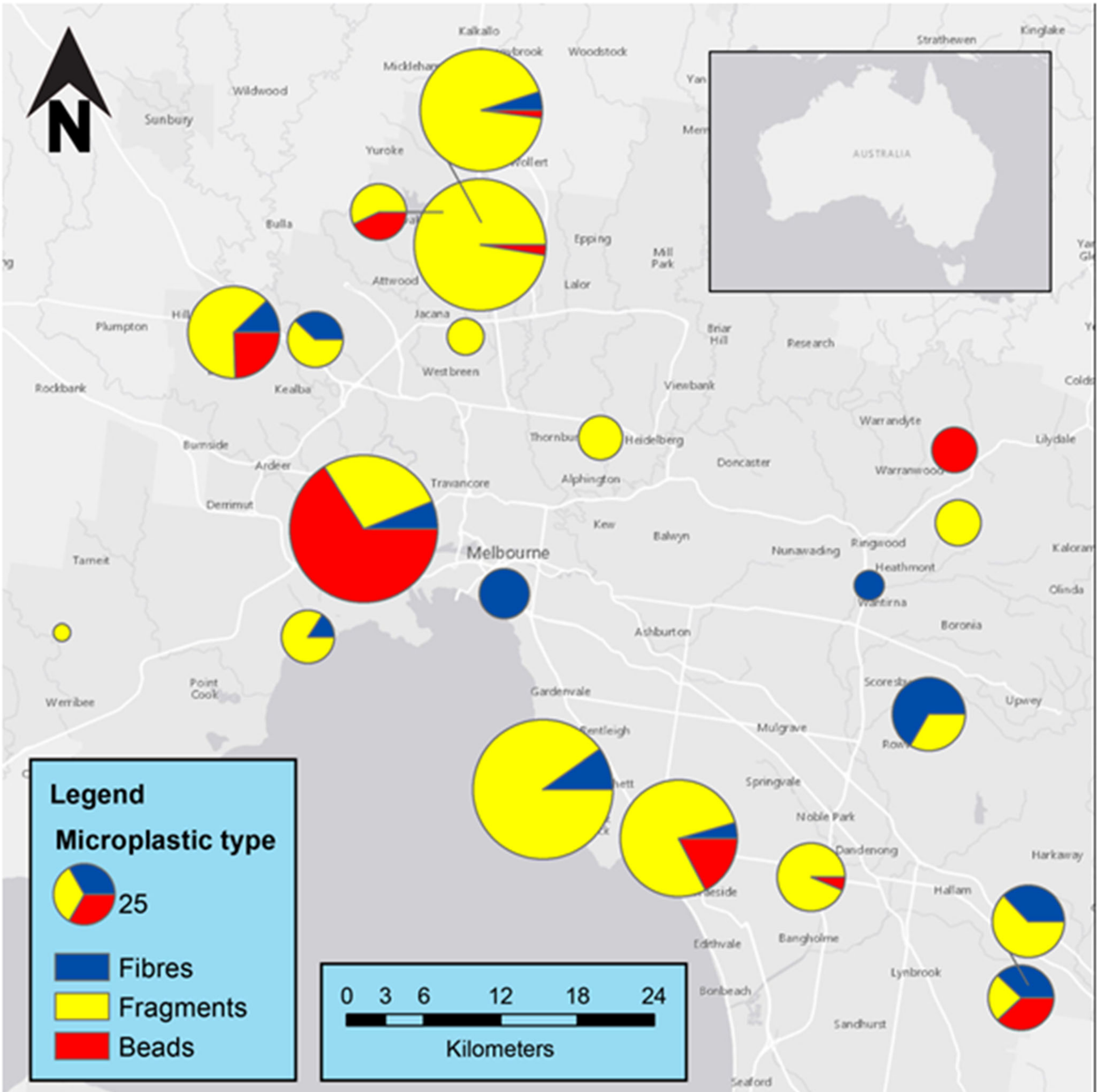

Fig. 1 Location of the urban wetlands surveyed in Melbourne, Australia. The size of each pie represents the total number of microplastics items found per kg of sediment. This figure was created in ArcMap 10.2.0.3348 using base layers from ESRI

polyvinylchloride and polyethylene terephthalate. Plastic fragments were < 1 mm in size (measured under a dissecting microscope). The plastic extraction procedure used was the same as the procedure described below for removing microplastics from wetland sediments. Plastic recoveries were repeated twice. Plastic recovery was always greater for $ZnCl_2$ than NaCl and was between 85 and 100% for all plastic types except acrylic (Table 1). There were no significant differences between the two density separation solutions except for acrylic, with significantly fewer pieces extracted from sediment using NaCl than $ZnCl_2$ (independent t test; $t = -9.04$, d.f. = 2, $P = 0.012$). Low replication may account for the lack of significant differences.

As $ZnCl_2$ was more effective for extracting microplastics from spiked sediment samples, it was used in all further extractions. Each sediment sample (500 mL of sediment) was weighed and sieved through 1-mm and 35-μm sieves. Sediment retained on the 35-μm sieve was transferred to a

Table 1 Plastic recovery (range, %) of different types of plastic fragments from an artificial sediment using NaCl and $ZnCl_2$ density separation techniques

Plastic	NaCl (%)	$ZnCl_2$ (%)
Polypropylene	60–80	90–100
Polyethylene	80	80–90
Acrylic	20	60–70
Polyvinylchloride	40–60	60–70
Polyethylene terephthalate	10	90

beaker using reverse-osmosis water. The sediment residue was dried overnight in an oven at 60 °C to remove excess water. Microplastics were then removed from the sediment residue using density separation with zinc chloride ($ZnCl_2$). A highly concentrated solution of $ZnCl_2$ was prepared by dissolving $ZnCl_2$ in deionised water to a density of 1.5 g/cm^3. The solution was added to the sediment sample, which was then vigorously stirred for 2 min and settled for 1 h. The supernatant was filtered through a 35-μm filter, and any $ZnCl_2$ waste was appropriately disposed of to avoid environmental contamination. Extraction with $ZnCl_2$ was only performed once per sample, with the results of the spiked recovery test and examination of the dense residue ensuring this was sufficient for extracting microplastics from the sediment samples. All residues were transferred from the filter to a petri dish and covered in parafilm to prevent contamination. The residues were examined under a dissecting microscope to pick out suspected microplastics. Microplastics were categorised into fibres, fragments and beads. Microplastics were identified and counted under a dissecting microscope at × 80 magnification using the criteria proposed by Norén (2007). Briefly, these were no cellular or organic structures visible within the particle; fibres should be equally thick (not taper at the ends) and have three-dimensional bending to ensure it is a plastic, not of biological origin; the plastic particle should be clear or homogenously coloured; and if it is not clear (if the particle is whitish), it should be examined under high magnification. In addition, fragments were often irregularly shaped with sharp, broken edges, while beads were rounded or subrounded and could be coloured, translucent or clear, including beads used in cosmetics or pre-cursors for plastic manufacturing. The identity of plastics was not taken further as this was only a preliminary investigation into microplastic contamination; plastic identification is proposed for future work. The abundance of microplastics at each wetland was calculated as the number of items per kilogram of dry sediment to allow comparisons to be made between wetlands and with other studies.

To prevent airborne contamination, we adopted procedures from Zhao et al. (2015) where all laboratory equipment was rinsed three times with distilled water before and after each use. Glassware and petri dishes were covered with aluminium foil immediately after being rinsed. A cotton laboratory coat and nitrile gloves were worn during the whole process. Work surfaces in the laboratory were cleaned with 70% ethanol prior to processing samples. Despite these practices, contamination of samples with microplastics (notably fibres) may still have occurred so data were interpreted cautiously, especially microplastic fibre data from samples where abundances were relatively low.

Statistical analysis

Statistical data analysis was performed using SPSS 22.0 software (IBM Co. Ltd., USA). A comparison between $ZnCl_2$ and NaCl recoveries was made for the different types of plastics in the spiked recovery test using independent *t* tests. Proportion recovered data were first arcsine square-root transformed then tested for normality using Kolmogorov-Smirnov tests prior to analyses. Associations between microplastic abundance and total catchment size, as well as microplastic abundance and land use type, were investigated with Spearman rank correlations using both the proportion of land use type and the absolute area of land use type in each catchment. Proportion data were arcsine square-root transformed before analysis. Relationships between microplastic abundance and population data were also conducted by correlating microplastic abundance with population size, population density and dwelling density in each wetland catchment. Catchment size and land use data were determined in ArcGIS 10.3 using layers provided by the Victorian Department of Environment, Land, Water and Planning, while population data for each catchment was calculated using data from Australian Bureau of Statistics (2011). Details of the methods for deriving land use and population data are given in Marshall et al. (2016) and Sharley et al. (2017).

Results

Microplastics were observed in sediment samples from all wetlands (Table 2). A total of 913 microplastics were counted, of which 120 were fibres, 625 were fragments and 168 were beads. Examples of these are given in Fig. 2. There was a large variation in microplastic abundance across the 20 wetlands, ranging from 2 items/kg dry sediment to 147 items/kg dry sediment (Fig. 1). Among the three microplastic types, fragments were most common, making up 68.5% of the microplastics detected and present at 85% of wetlands. Fibres and beads were found in sediment samples from 60% and 45% of wetlands respectively. At seven sites, only a single type of microplastic was found (Fig. 1).

When microplastic abundance in sediment was correlated with the different land use types (as a proportion of catchment

Table 2 Microplastic abundance (items/kg dry sediment) in sediment from urban wetlands in Melbourne, Australia

Wetland Name	Microplastic abundance			
	Total	Fibres	Fragments	Beads
Croydon Main Drain Wetland	14	0	14	0
Berwick Springs Lake	35	13	22	0
Jack Roper Lake	9	0	9	0
Cherry Lake	19	3	16	0
Cala St Ponds	147	9	41	97
Avoca St Retarding Basin	132	13	119	0
Austrak Retarding Basin	101	5	94	2
Southern Road Retarding Basin	92	4	72	16
Albert Park Lake	17	17	0	0
Chandler Rd Retarding Basin	31	0	29	2
Darebin Ck Park Wetland	13	0	13	0
Naganthan Way Pond	14	0	0	14
St Clair Blvd Wetland	21	0	12	9
National Business Park Wetland	117	0	114	3
The Esplanade Wetland	29	11	7	11
Yarrabing Wetland	6	6	0	0
Taylors Lakes Retarding Basin	21	8	13	0
Lysterfield West Retarding Basin	36	24	12	0
Watergardens Wetlands	57	7	36	14
Riversdale Drive Wetland	2	0	2	0
Average	45.65	6.00	31.25	8.40
Standard deviation	45.59	6.82	37.81	21.60

area within each wetland catchment), the abundance of microplastics was negatively correlated with the proportion of open space (Spearman rank correlation; $\rho = -0.79$, $P < 0.001$, $N = 20$; Fig. 3a); i.e. the less developed a catchment was, the fewer microplastic items were found in wetland sediments. This negative association with open space was also significant for microplastic fragments ($\rho = -0.70$, $P = 0.001$, $N = 20$; Fig. 3b) and to a lesser extent microplastic beads ($\rho = -0.52$, $P = 0.02$, $N = 20$; Fig. 3c). There was a positive correlation between microplastic fragment abundance and the proportion of industrial area in a catchment ($\rho = 0.61$, $P = 0.004$, $N = 20$; Fig. 3d). Other land use types did not significantly correlate with microplastic abundances in wetland sediment (Table 3).

The amount of industrial area within a wetland catchment was positively correlated with microplastic fragment abundance ($\rho = 0.46$, $P = 0.04$, $N = 20$). Other land use types, when considered by area, did not significantly correlate with microplastic abundances (Table 4). Dwelling density within wetland catchments had a positive correlation with plastic fragment abundance ($\rho = -0.46$, $P = 0.04$, $N = 20$; Fig. 3e). Microplastic abundance was not associated with population size or population density in a wetland catchment (Table 5).

There were no significant correlations between catchment size and microplastic abundances when total microplastics or

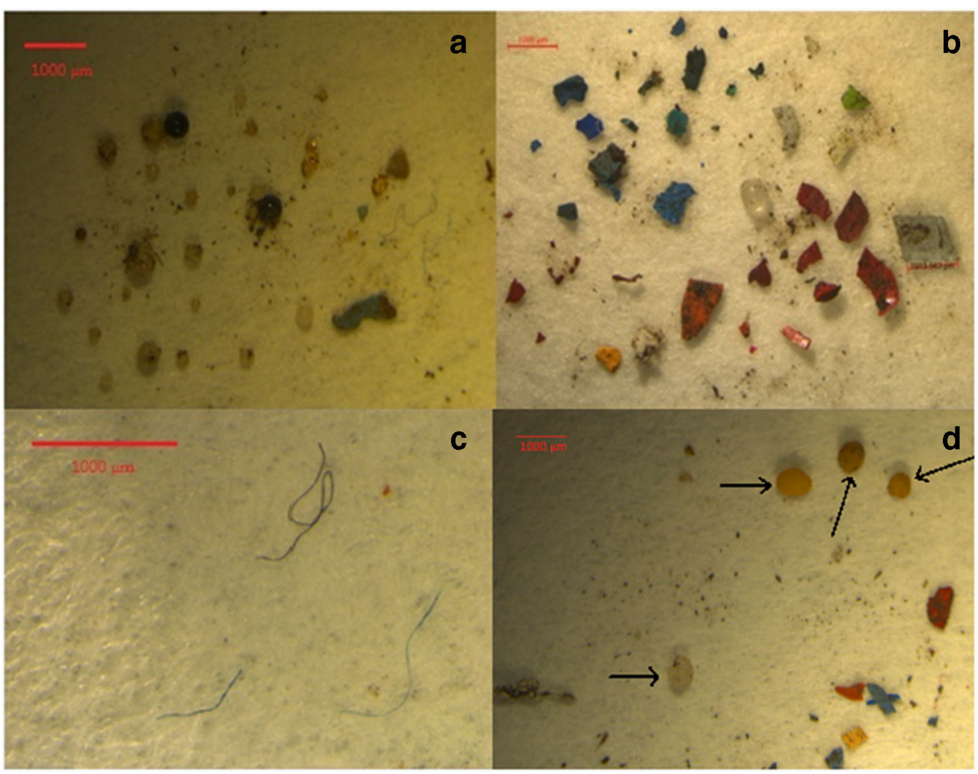

Fig. 2 Examples of microplastics found at different wetlands. **a** Microbeads from Cala St Ponds. **b** Coloured fragments from National Business Park Wetland. **c** Fibres from Albert Park Lake. **d** Microbeads (indicated by arrows) and fragments from Southern Road Retarding Basin

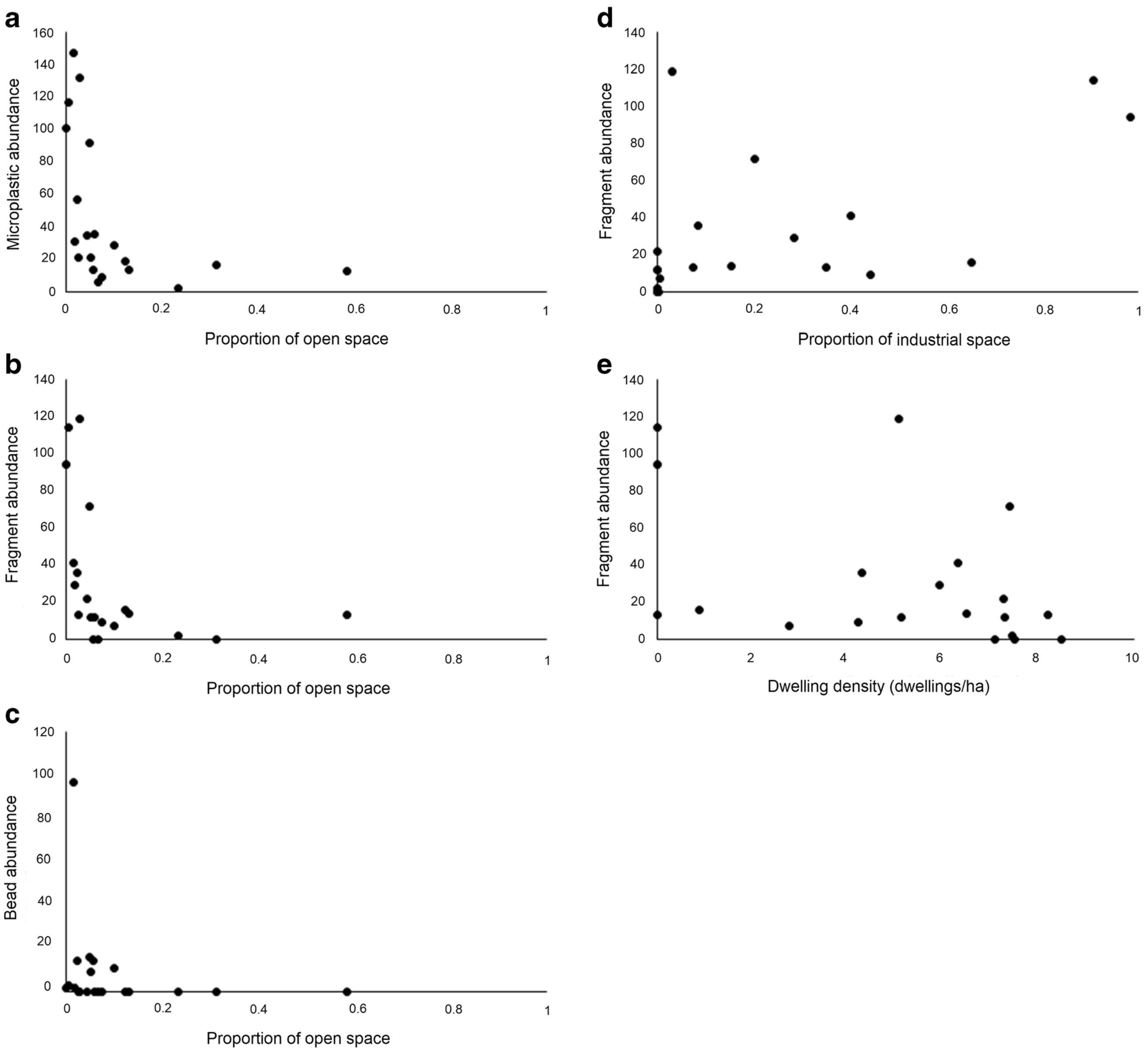

Fig. 3 Associations between **a** total microplastic abundance (items/kg dry sediment) and proportion of open space in a wetland catchment, **b** microplastic fragment abundance (items/kg dry sediment) and proportion of open space in a wetland catchment, **c** microplastic bead abundance (items/kg dry sediment) and proportion of open space in a wetland catchment, **d** microplastic fragment abundance (items/kg dry sediment) and proportion of industrial area in a wetland catchment and **e** microplastic fragment abundance (items/kg dry sediment) and dwelling density (dwellings/ha) in a wetland catchment

individual classes of microplastics were considered ($\rho = 0.25$–0.33, $P > 0.05$, $N = 20$).

Discussion

Microplastics were present in sediment at all urban wetlands, with abundances like those reported in other studies around the world (Table 6). Importantly, this study has shown that urbanisation was strongly associated with microplastic pollution. Increasing urban development within a catchment was correlated with increased microplastic abundance in sediments, as demonstrated by the strong negative association between the proportion of open space in a catchment and microplastic abundance. Such a relationship between microplastic pollution and urban activities has been shown in other studies. For example, the types and distribution of microplastics in water samples from the Laurentian Great Lakes, USA, indicated nearby urban activities were the source of microplastic pollution (Eriksen et al. 2013). Similarly,

Table 3 Correlation coefficients (ρ) for Spearman rank correlations between microplastic abundance (items/kg dry sediment) and proportion urban land use type within a wetland catchment (arcsine square-root transformed)

Microplastic	Commerce	Industrial	Open	Residential	Road/ rail	Rural	Semi-rural	Urban growth
Total	0.25	0.34	− 0.79**	−0.24	−0.01	− 0.06	0.17	− 0.08
Fibres	0.34	− 0.29	− 0.12	0.05	0.17	0.21	0.37	0.41
Fragments	0.16	0.61*	− 0.70**	− 0.41	− 0.02	− 0.17	0.03	− 0.40
Beads	− 0.001	0.17	− 0.52*	0.03	− 0.12	− 0.15	− 0.02	0.05

*Significant correlation ($P < 0.05$). **Strongly significant correlation ($P < 0.001$). $N = 20$

Cable et al. (2017) also found microplastic pollution was greatest within 12 km of urban cities, river plumes (from rivers with human activities) or in WWTP effluents in Lake Erie. Microplastic abundances in estuaries of Chesapeake Bay, USA, were positively correlated with population density and urban development within the watersheds of those estuaries (Yonkos et al. 2014).

While concern about microplastic pollution continues to grow, much of the attention surrounding microplastics has focussed on wastewater treatment plant (WWTP) effluent as a significant source of microplastics (e.g. Browne et al. 2011). A positive response to this has been the phasing out of microbeads in consumer products at corporate, national and international levels (e.g. the 'Microbead-Free Waters Act of 2014' in the USA, 113th Congress (2013–2014)). Although beneficial, these initiatives cannot completely address microplastic pollution for two main reasons. Firstly, beads from consumer products are not the only microplastics entering the environment. Free et al. (2014) found secondary microplastics (the breakdown products of larger plastic items, such as fragments) were the most abundant microplastics in a remote mountain lake, while very few beads or pellets were detected. Similarly, we also found fragments were the most common type of microplastics in urban wetland sediments. Beads are often associated with WWTP effluents, but even then, fibres from washing synthetic clothes, rather than beads, dominate the microplastics measured (Browne et al. 2011; Table 6).

The second reason is that wastewater effluent is not the sole source of microplastics to aquatic ecosystems. The wetlands we examined receive significant stormwater inputs and little, if any, discharges from domestic wastewater, so stormwater is the likely source of these microplastics. The presence (and even dominance) of beads in some sites could suggest that sewage is entering the wetland, such as through illegal cross connections or damaged sewerage infrastructure allowing sewage to enter the stormwater network. However, plastic beads have been found around industrial premises where plastics are manufactured; from here, they ended up in the stormwater network and eventually made it into receiving waters such as Melbourne's Port Phillip Bay (O'Shea et al. 2014). In the Great Lakes, plastic pellets and beads were not associated with wastewater but with other urban attributes (urban land cover, imperviousness and population density) (Baldwin et al. 2016). In urban environments, stormwater is a significant source of pollutants, including microplastics, to aquatic ecosystems (Ryan et al. 2009). Yonkos et al. (2014) found the greatest concentrations of microplastics in estuaries occurred after rainfall events, highlighting the role stormwater plays in microplastic pollution. Microplastic abundances were higher during wet conditions than dry conditions in stormwater-affected urban rivers in southern California, USA, even after light rain (Moore et al. 2011). Similarly, secondary microplastics from litter were more abundant in Great Lakes tributary samples from urban watersheds and during runoff events, presumably because impervious surfaces and stormwater systems effectively convey these microplastics to tributaries during rainfall (Baldwin et al. 2016). Efforts to reduce microplastic pollution in urban environments must address stormwater as a source of microplastics to aquatic environments.

In Melbourne, as in other parts of the world, wetlands have been used as a means of protecting aquatic ecosystems from stormwater pollution (Malaviya and Singh 2012; Sharley et al. 2017). The premise here is that stormwater enters the wetland

Table 4 Correlation coefficients (ρ) for Spearman rank correlations between microplastic abundance (items/kg dry sediment) and land use type (area, ha) in each wetland catchment

Microplastic	Commerce	Industrial	Open	Residential	Road/ rail	Rural	Semi-rural	Urban growth
Total	0.17	0.25	− 0.10	0.16	0.16	− 0.06	0.16	− 0.08
Fibres	0.35	− 0.14	0.37	0.40	0.29	0.21	0.37	0.41
Fragments	0.14	0.46*	− 0.17	0.04	0.08	− 0.16	0.02	− 0.40
Beads	0.03	0.20	− 0.15	0.15	0.17	− 0.15	− 0.05	0.05

*Significant correlation ($P < 0.05$). $N = 20$

Table 5 Correlation coefficients (ρ) for Spearman rank correlations between microplastic abundance (items/kg dry sediment) and population data for each wetland catchment

Microplastic	Population density	Dwelling density	Population	Number of dwellings
Total	− 0.18	− 0.25	0.14	0.11
Fibres	0.13	0.28	0.37	0.39
Fragments	− 0.36	− 0.46*	0.02	0.01
Beads	− 0.02	− 0.12	0.16	0.10

*Significant correlation ($P < 0.05$). $N = 20$

and is retained for a period of time before passing through to a receiving ecosystem, such as a river or the sea. While in the wetland, physical and biological processes help to remove many pollutants from stormwater. Pollutants commonly removed from stormwater include sediments, nutrients, metals, organic contaminants and litter (Marshall et al. 2016; Sharley et al. 2017). While some pollutants may break down in the wetland, many accumulate in wetland sediment. As a result, urban wetlands can provide a useful means of measuring what pollutants are being generated in urban environments and where they are being generated. The results of our study showed microplastics were being generated by all urban activities and were entering the environment via stormwater. The dominance of fragments indicated plastic litter degradation was the major source of microplastics in the urban environment. Other studies have also shown that fragments are the dominant type of microplastic found in sediments affected by stormwater discharges (Table 6 and references within).

While microplastics were present in all urbanised areas, the positive association between fragment abundance and increasing industrialisation suggested that industrial activities may be contributing more plastic pollutants (i.e. litter) to the environment than other urban activities. In fact, national and state-wide litter surveys in Australia have identified industrial sites as the areas with the greatest volumes of litter and the second greatest abundances of litter per unit area (Keep Australia Beautiful, McGregor Tan Research 2014). Further evidence that litter degradation was a major source of plastic contamination in industrial areas came from sites where only a single type of microplastic was found. Wetlands where fragments were the only type of microplastic found in sediment had catchments with a large percentage of industrial area (> 15%), while those that only had beads or fibres had little to no industrial activity but had large proportions of residential or open space land uses. The association between microplastic pollution and industrial activities may also occur in other urban areas around the world. For example, Yonkos et al. (2014) also found a weak positive correlation between percentage urban/industrial area and microplastic pollution in an estuary.

The occurrence of microplastics in the sediments of urban wetlands demonstrates how these wetlands could prove useful for removing microplastics before stormwater enters receiving environments. However, further work is needed to understand the efficiency of urban wetlands at removing microplastics from stormwater, especially plastics with low densities (such as polystyrene) that will not accumulate in sediments unless they have been retained in the wetland for a sufficiently long period, such that biofilms or other particles have attached to them and increased their density. As such, urban wetlands will probably not protect downstream ecosystems from all types of plastics. This also highlights a limitation with the current study where, by only examining sediments for microplastics, the overall microplastic problem in urban wetlands was underestimated.

While microplastic accumulation in urban wetlands may afford some protection for receiving environments, it is also problematic. Although the primary purpose of many urban wetlands is to protect other aquatic ecosystems from stormwater pollution, these wetlands can have significant ecological values. Urban wetlands provide important habitat for many terrestrial, amphibious and aquatic species in an otherwise hostile urban landscape. However, these wetlands can act as ‘ecological traps’, with pollutant accumulation within wetlands adversely affecting the biota they attract (Hale et al. 2015). Although the effects of microplastics on wetland biota are largely unknown, biological impacts observed in other aquatic ecosystems would suggest that adverse effects in wetland biota are also likely.

In addition, urban wetlands could be potential sources of microplastic pollution to downstream ecosystems. In the absence of appropriate maintenance, such as regular litter removal, large pieces of plastics in wetlands or associated structures (e.g. gross pollutant traps) may degrade and become a source of microplastic fragments. Meanwhile, any microplastics accumulated in wetland sediments could be resuspended and redistributed during disturbance events, such as large floods. Wetland managers need to consider how to manage and maintain urban wetlands to ensure these do not become a significant source of microplastics. For example, gross pollutant traps could be installed and regularly maintained on wetlands that receive high litter loads, have high ecological values or protect downstream environments with high ecological values to reduce microplastic generation from litter breakdown. Alternatively, an end-of-system filtration structure could be installed to ensure that microplastics within the wetland are not released into downstream ecosystems.

Table 6 Comparison of microplastic abundance (items/kg dry sediment) and dominant types of microplastics found in sediments

Location	Habitat type	Microplastic abundance	Dominant microplastics	Identified sources	Reference
Melbourne, Australia	Wetlands	2–147	Fragments	Larger plastic items	Current study
Three Gorges Reservoir, China	Reservoir	25–300*	Fibres	Wastewater treatment plant effluent, larger plastic items	Di and Wang 2018
Venice, Italy	Lagoon	672–2175	Fragments	Larger plastic items	Vianello et al. 2013
Bizerte, Tunisia	Lagoon-channel	3000–18,000	Fibres	Wastewater treatment plant effluent, larger plastic items	Abidli et al. 2017
Changjiang Estuary, China	Estuary	20–340	Fibres	Wastewater treatment plant effluent	Peng et al. 2017
Scapa Flow, Scotland	Intertidal zone	730–2300	Fibres	Wastewater treatment plant effluent, marine litter	Blumenröder et al. 2017
Isle of Rügen, Germany	Beaches	63–106	Fibres	None identified/-speculated	Hengstmann et al. 2018
Europe	Beaches	72–1512	Fibres	Wastewater treatment plant effluent, marine litter	Lots et al. 2017
Southeastern USA	Beaches	< 60–300	Fibres	Wastewater treatment plant effluent	Yu et al. 2018
Lake Ontario, Canada	Nearshore	20–27,830	Fragments and fibres	Wastewater treatment plant effluent, stormwater discharge	Ballent et al. 2016
Persian Gulf, Iran	Coastal zone	0–125	Fibres	Wastewater treatment plant effluent, fishing	Naji et al. 2017
Hong Kong	Coastal zone	49–279	Fragments	Wastewater treatment plant effluent, stormwater discharge, illegal dumping, accidents	Tsang et al. 2017
Southern Baltic Sea	Marine and beach	25–53	Fibres	Wastewater treatment plant effluent, larger plastic items	Graca et al. 2017
Tyrrhenian Sea, Italy	Marine and coastal	62–466	Fibres	Not specified	Cannas et al. 2017
Baltic Sea	Marine zone	12–48	Fibres	Not specified	Zobkov and Esiukova 2017
The Netherlands	Sewage sludge	510–760*	Fibres	Wastewater treatment plant	Leslie et al. 2017
Ireland	Sewage sludge	4196–15,385	Fibres	Wastewater treatment plant	Mahon et al. 2017

*Wet sediment or sludge

Conclusions

Microplastics are a common occurrence in urban wetlands that receive stormwater loads and are associated with an increase in urban activities within wetland catchments. Fragments are the dominant type of microplastic found in wetland sediments, especially in more industrialised catchments. The presence of microplastics in urban wetland sediments does suggest that urban wetlands may offer some protection to downstream ecosystems by removing denser microplastics but may detrimentally affect biota that inhabit these wetlands. Using wetland sediments to monitor pollution can assist environmental managers with identifying problem catchments and land use activities that contribute most to pollution. In the current study, the dominance of microplastic fragments suggests that plastic litter is a significant source of microplastic pollution, which could be managed by reducing litter loads within increasingly urbanised catchments, especially those with a high proportion of industrial activity. The study also raises questions about urban stormwater and wetland management, such as the following: how efficient are urban wetlands at removing microplastics and protecting downstream ecosystems from microplastic pollution; are microplastics adversely affecting the ecological values of urban wetlands; and are urban wetlands a potential source of microplastics to downstream ecosystems?

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