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Microplastic contamination in the San Francisco Bay, California, USA

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ABSTRACT

Despite widespread detection of microplastic pollution in marine environments, data describing microplastic abundance in urban estuaries and microplastic discharge via treated municipal wastewater are limited. This study presents information on abundance, distribution, and composition of microplastic at nine sites in San Francisco Bay, California, USA. Also presented are characterizations of microplastic in final effluent from eight wastewater treatment plants, employing varying treatment technologies, that discharge to the Bay. With an average microplastic abundance of 700,000 particles/km^2, Bay surface water appears to have higher microplastic levels than other urban waterbodies sampled in North America. Moreover, treated wastewater from facilities that discharge into the Bay contains considerable microplastic contamination. Facilities employing tertiary filtration did not show lower levels of contamination than those using secondary treatment. As textile-derived fibers were more abundant in wastewater, higher levels of fragments in surface water suggest additional pathways of microplastic pollution, such as stormwater runoff.

1. Introduction

While plastic pollution of the marine environment has been reported for decades, only recently have estuaries and freshwater systems been a focal point of similar studies (Dubaish and Liebezeit, 2013; Eriksen et al., 2013; Castañeda et al., 2014; Free et al., 2014; Yonkos et al., 2014; Davis and Murphy, 2015). A key component of this pollution, microplastic describes fragments of plastic that are smaller than 5 mm (Thompson et al., 2009; Masura et al., 2015). Sources of microplastic to the environment include microbeads used in personal care products, pre-production pellets used as precursors to manufacture plastic products, fibers derived from clothes and fabrics made with synthetic materials (e.g., polyester and acrylic) or fishing line, fragments from the photodegradation of larger plastic items, and plastic foam particles from polystyrene products or cigarette filters (Fendall and Sewell, 2009; Browne et al., 2011; Eriksen et al., 2013; Free et al., 2014; van Franeker and Law, 2015). Microplastic can enter the aquatic environment through wind advection, stormwater runoff, or illegal dumping of plastic materials (Eriksen et al., 2013). Additionally, both microbeads from personal care products and fibers from synthetic clothing can be washed down the drain and enter wastewater treatment plants, where their small size, buoyancy, and lack of reactivity limits removal, resulting in release via treated wastewater (Browne et al., 2011; NYS OAG, 2015).

Microplastic particles pose risks to wildlife because the particles may be mistaken for food and ingested (Wright et al., 2013). The particles are also small enough that they can be ingested by planktonic organisms and other filter feeders (Browne et al., 2008; Cole et al., 2013). The hydrophobicity and high surface area to volume ratio of microplastic particles leads to sorption of persistent organic pollutants such as polycyclic aromatic hydrocarbons (Teuten et al., 2007). Organisms that ingest microplastic particles may thus receive higher doses of sorbed contaminants, potentially causing additional harm (Wright et al., 2013). Ingestion of microplastic can block the digestive tract, reduce growth rates, block enzyme production, lower steroid hormone levels, affect reproduction, and may lead to greater exposure to plastic additives with toxic properties (Wright et al., 2013).

Despite widespread detection of microplastic pollution in the marine environment, data describing microplastic abundance in urban estuaries and microplastic discharge via treated municipal wastewater are limited. This initial, screening study characterized microplastic in treated wastewater effluent from eight facilities employing a range of treatment technologies and discharging to San Francisco Bay, hereafter referred to as the Bay. Treated wastewater is considered an important

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pathway for microplastic to enter receiving waters, but only a few studies of this matrix are available (Carr et al., 2016; Mason et al., in review). In addition, this study provides data on microplastic in surface waters of the Bay, the largest estuary on the west coast of North America, which is surrounded by a dense urban population and drains roughly 40% of the waters of California.

2. Materials and methods

2.1. Wastewater

Treated wastewater is discharged to San Francisco Bay from more than 30 different discharge locations. Eight facilities, providing approximately 60% of measured wastewater flows directly to the Bay, permitted researcher access to final effluent sinks or other available ports, allowing us to collect samples. Samples of microplastic discharged from wastewater treatment plants were collected by passing flows of final, treated effluent through 8-in. diameter stacked Tyler sieves with 0.355 mm and 0.125 mm stainless steel mesh, typically for 2 hours during each facility's peak flow. The 0.125 mm mesh has been found to be particularly useful for retention of microbeads discharged to the sewer via use of personal care products (Napper et al., 2015; Carr et al., 2016). A single set of two samples, differentiated by sieve mesh size, was collected in the fall of 2014 at each of the eight facilities. Facilities participated voluntarily, and were selected based on multiple factors, including higher discharge levels, geographic diversity, and range of treatment technologies (secondary vs. tertiary filtration; Table 1). Rate of flow at the point of collection was measured before and after each sample was obtained (to ensure consistency), allowing calculation of number of particles per volume of treated wastewater. Each facility provided the 24-h discharge flow rate for the day of sample collection, allowing estimation of the number of particles discharged to the Bay per day.

In order to remove labile organic material, samples were processed via a wet peroxide oxidation (WPO) based upon a National Oceanic and Atmospheric Administration method (Masura et al., 2015), which has been tested to ensure that the most common plastic materials survive. Briefly, samples were reacted with a 30% hydrogen peroxide solution in the presence of an iron (II) catalyst in order to oxidize natural organic material, leaving the synthetic plastic material behind. Wastewater samples were processed as individual samples according to the collected size classification (i.e., 0.125–0.355 mm or >0.355 mm).

After processing, samples were once again filtered though a stacked sieve set (0.355 mm and 0.125 mm) and rinsed using deionized (DI) water into petri dishes. Given their density relative to that of DI water and most natural materials, floating particles within this medium are assumed to be plastic, a common technique within this field of research (Hidalgo-Ruz et al., 2012; Rocha-Santos and Duarte, 2014). Using a dissection microscope, plastic particles were removed, enumerated, and categorized into five classifications: fragment, pellet (spherical particle), fiber/line, film or foam (Free et al., 2014; McCormick et al., 2014). While instrumental analysis methods such as infrared or Raman spectroscopy are necessary for polymeric identification (i.e., polyethylene versus polypropylene), numerous studies have employed only visual identification for microplastic classification (e.g., Bond et al., 2014; Lavers et al., 2014; Devriese et al., 2015; Rochman et al., 2015; Romeo et al., 2015; Fossia et al., 2016; Hammer et al., 2016; Miranda and Carvalho-Souza, 2016; Nicolau et al., 2016; Peters and Bratton, 2016). Given the source (i.e., wastewater), fibers obtained in this processing would presumably be anthropogenic and derived from textiles, though a portion of fibers observed in wastewater may not be plastic, instead derived from other anthropogenic sources (Remy et al., 2015; Nirmela Arsem, personal communication).

2.2. Surface water

Single surface water microplastic samples were collected from each of nine sites in San Francisco Bay over the course of 2 days in January 2015 (Fig. 1). Central and southern portions of the Bay contain higher levels of litter, including macroplastic debris, than northern stretches, and were the focus of this study (Rubissow-Okamoto, 2014). During sample collection, conditions were calm: the sea state on the Beaufort

Table 1
Microplastic particles present in treated wastewater, and estimates of discharge per liter and per day.

				No. plastic particles by type						No. plastic particles	
Wastewater treatment plant	Flow[a] (MLD)	Highest level of treatment	Size category (mm)	Fragment	Pellet	Fiber	Film	Foam	Total	Per liter[b]	Per day[a]
San José-Santa Clara	310	Tertiary filtration	0.125–0.354	0	0	26	0	0	26		
			≥0.355	0	0	33	0	0	33		
			total	0	0	59	0	0	59	0.047	15,000,000
East Bay Municipal Utilities District (EBMUD)	170	Secondary	0.125–0.354	1	0	11	1	0	13		
			≥0.355	7	0	5	3	0	15		
			total	8	0	16	4	0	28	0.071	12,000,000
Palo Alto	76	Tertiary filtration	0.125–0.354	3	0	24	0	0	27		
			≥0.355	8	0	23	2	0	33		
			total	11	0	47	2	0	60	0.13	9,600,000
Central Contra Costa	110	Secondary	0.125–0.354	21	0	28	0	0	49		
			≥0.355	5	0	10	0	0	15		
			total	26	0	38	0	0	64	0.072	8,100,000
Fairfield-Suisun	45	Tertiary Filtration	0.125–0.354	2	0	43	0	0	45		
			≥0.355	2	0	50	2	0	54		
			total	4	0	93	2	0	99	0.092	4,100,000
East Bay Dischargers Association (EBDA)	190	Secondary	0.125–0.354	1	0	11	0	0	12		
			≥0.355	1	0	9	0	0	10		
			total	2	0	20	0	0	22	0.022	4,100,000
San Mateo	31	Tertiary filtration	0.125–0.354	20	0	24	0	3	47		
			≥0.355	7	0	21	3	0	31		
			total	27	0	45	3	3	78	0.064	2,000,000
San Francisco Airport Sanitary (SFO)	2.3	Secondary	0.125–0.354	5	0	49	0	0	54		
			≥0.355	4	0	42	0	1	47		
			total	9	0	91	0	1	101	0.19	460,000
Total count			total	87	0	409	11	4	511		
Percentage by type			total	17%	0%	80%	2%	1%	100%		

[a] Measured discharge on day of sample collection, used to calculate plant discharge per day.
[b] Calculated using average flow rate at point of sample collection, see Supplementary Content.