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Microplastics in freshwater environments: A review of quantification assessment

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ABSTRACT

Microplastic (MP) studies in freshwater environments are gaining attention due to the huge quantities of plastic particles reported from lakes and rivers and the potential for negative impacts in these environments. Different units have been used to report MP densities, which makes it difficult to compare data and can result in reports of extremely high concentrations that do not reflect the original sample size. We recommended that the density of MPs from bulk samples be reported as number L^{-1}, while density from net samples should be reported as number m^{-3}. If the density of MPs from net samples is expressed on an areal basis, values should be reported as number/1000 m^2, and not as number km^{-2}. Spectroscopy (ATR-μFT-IR and μRAMAN) and Pyrolysis-Gas Chromatography coupled to Mass Spectrometry are techniques that could be used for quantitative identification of the various types of polymers in MP particles.

1. Introduction

Plastic products are used by most societies worldwide and their production has increased dramatically since their initial commercial development in the 1950s with over 335 million tons produced globally in 2016 [1]. Currently, there are no signs indicating any future decrease in the production of these synthetic polymers that are derived from crude oil. This situation occurs due to the fact that plastics are used instead of natural materials like glass, metal, leather, paper or wood because they are durable, cheap and easily discarded. Plastic debris in the ocean has received a lot of attention since it was first reported in the 1970s [2] and has been studied extensively since approximately 2005 [3,4]. Macroplastics are readily visible and known for their negative social, economic and ecological impacts. Some examples include the degradation of tourist areas, and floating macroplastics that cause boat accidents by entanglement and damage of equipment. The costs of cleaning beaches are high, and this it is not the solution to plastic debris issues [5]. Marine ecosystems and their organisms are being adversely affected; one example of this anthropogenic pollution is the North Pacific Gyre [6]. Plastic debris pollution is distributed from pole to pole, the Arctic [7,8] to the Antarctic [9,10], and it is of

great concern to social and scientific communities. There are a series of summaries of this research topic in the oceans and freshwater environments [11]. These studies of plastic debris contamination have demonstrated a clear threat for these environments, the biota and possibly human health. Plastic debris in freshwater systems has recently become an intense topic of study and a major focus has been determining the lakewide abundance of microplastics (MPs) particles, e.g. Laurentian Great Lakes [12].

Determination of the density, size distribution, and composition of MP particles in aquatic systems is a relatively new endeavor and presents some challenges for developing standardized sampling and reporting methods. It is important to recognize that MPs are not evenly distributed vertically or horizontally in the water column and their abundance will decrease at greater distances from the source of their introduction. MPs will settle out of the water column at different rates depending on their density, potential for accumulating a biofilm, and the prevailing water currents. Their final fate and distribution in both marine and freshwater environments is still unknown.

Standard methods have been developed for assessing the abundance of living organisms in aquatic ecosystems, and researchers employ a variety of qualitative or quantitative sampling techniques depending on the size, density, and distribution patterns of their target entities as well as their study objectives [13,14]. In general, sample sizes are selected to ensure the collection and quantification of a fairly large number of organisms from each

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sample. Final densities or concentrations of organisms in the environment are then reported in units that reflect the original sample size. For example, microbiologists often filter a minimum of 100 mL of water and report microbial concentrations as number of colonies/100 mL. Phytoplankton and protists are examined in replicate 1 mL subsamples from 500 to 1000 mL of water and densities are reported as number mL^{-1} of original sample water. Zooplankton samples are often collected with fairly large nets (0.5 m in diameter) that filter several cubic meters of water and results are then reported as number m^{-3}, or for vertical tows as number m^{-2}.

In order to understand how authors are currently sampling and calculating the abundances of MPs in the surface waters of freshwater systems, we examined several peer reviewed papers that reported concentrations or abundances of MPs. Through this review, we hoped to develop a list of suggestions for analysis and reporting conventions so that data on freshwater MP abundance can be more readily compared.

2. Microplastic assessment

2.1. Microplastics

MPs are defined as plastic particles smaller than 5 mm [15], however, there has been some inconsistency in the lower size limit for classifying particles as MPs, with some authors including all particles greater than 1 nm. In this paper, we are using the European Commission's definition of nanosize particles as the size range from 1 to 100 nm and MPs as particles between 100 nm and 5 mm in size. MPs are often found in freshwater as filaments/fibers, films, fragments, spheres/pellets and foams and occur in a variety of colors.

MPs are produced in intentional ways, such as virgin pellets or preproduction plastics, microbeads from cosmetic products, abrasives used in air/water-blasting for cleaning, and as powders for injection molding, medicine, or ink for 3D printers. Unintentional means of producing MPs include fragmentation of macroplastic products by exposure to sunlight, mechanical action, animal interaction, or from biosolids and effluents from Wastewater Treatment Plants. These MPs then enter oceans, rivers, and lakes [16,17]. MPs adsorb a diverse variety of persistent organic pollutants [18] and heavy metals [19] from the environment and at the same time can desorb plasticizers or other additives that were incorporated in the plastic products [20]. However, to what extent and at what concentration MPs can be a source of these toxic compounds to organisms in freshwater systems remains unknown. MPs (Fig. 1) can be confused with natural food and can be ingested by organisms such as fish, mussels, and birds (e.g. Refs. [21,22]).

The collection and analysis of MPs present several challenges due to their variable sizes, shapes, colors, chemical composition, and ability to adsorb/desorb toxic compounds. Macroplastic abundance (8 million tonnes per year) in the oceans has been estimated based on population size and the degree of mismanagement of the plastic waste that has been generated on land [23]. MP studies in freshwater systems started in 2013 [12] and now there are reports from freshwater environments from around the world, although some of these reports are based on only a few samples. It is very difficult to calculate the total MP concentrations in freshwater systems and to compare one system to another due to a lack of consensus on protocols for identifying the polymers in MP-like particles and for reporting their concentrations. It is imperative to reliably count and identify MPs in freshwaters in order to assess their threat in these environments. Harmonization of methods is one of the priorities for researchers who are estimating the extent of MP pollution.

2.2. Concentration

As with the study of other contaminants, quality controls must be used when collecting and analyzing MPs, including the use of blanks in the field and during the lab analysis. Airborne fibers are the most common source of contamination during the processing of samples in the lab and can result in an overestimation of abundance of MPs.

A review of the literature showed that different methods of collecting and analyzing MPs from freshwater systems are employed depending on the study objectives. Pumps, steel or polycarbonate sampling tubes, or buckets have been used to collect bulk water samples from the surface or from different depths (e.g. 0—18 cm) in lakes and rivers to determine the total abundance and vertical distribution of MP particles in the water column (Table 1). While the volume of individual samples was generally fairly small (0.3—25 L), the samples were filtered through very fine mesh (2.7—63 μm), thus each sample retained a fairly large number of very small MP particles, including thin fibers. Su et al. [24] reported MP density as number of particles L^{-1} with concentrations ranging from 3.4 to 25.8 particles L^{-1}. Schmidt et al. [25] also reported MP density as number of particles L^{-1}, and found concentrations of 0.01—95.8 particles L^{-1}, even though they only included particles greater than 450 μm in size in their analyses (Table 1). Other authors [26—29] included the smaller particle size classes and reported the total density of MPs in the water column as number of particles m^{-3} (1000 L) of water. They reported MP concentrations ranging from 1660 to 519,000 particles m^{-3} (Table 1).

It should be noted that although the actual number of MP fibers found in each of the individual samples collected by Lahens et al. [29] only ranged from 51 to 140, their reported densities of
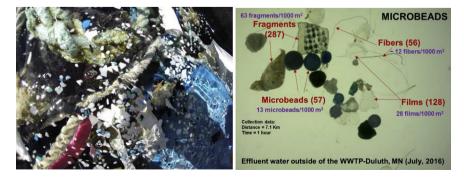

Fig. 1. Macro and microplastics from a) Pacific Ocean from the area known as "eastern garbage patch" and b) River (St. Louis River Estuary, USA).

Table 1
Data from small volume bulk samples reported as MP particles L^{-1} or particles m^{-3}.

Reference	Location	Collection method	Volume Sampled (L)	Filtration Mesh (μm)	Reported values	[a]Standardized to particles L^{-1}
[24]	Taihu Lake, China	Bulk surface water sample	5	5	3.4–25.8 L^{-1}	3.4–25.8
[25]	Teltow Canal, Berlin, Germany	Bulk surface water sample, top 5 cm	average 12.4 per sample	63	[b]0.01–95.8 L^{-1}	0.01–95.8
[26]	Lakes and Rivers in Wuhan, China	Pumped from top 20 cm	20	50	1660–8925 m^{-3}	1.6–8.9
[27]	Dongting and Hong Lakes, China	Pumped from top 20 cm	20	50	900–4650 m^{-3}	0.9–4.65
[28]	Three Gorges Reservoir China	Pumped from depth of 1 m	25	48	1597–12,611 m^{-3}	1.6–12.6
[29]	Saigon River, Vietnam	Bulk surface water sample	0.300	2.7	[c]172,000–519,000 m^{-3}	172–519

[a] Data calculated by authors.
[b] Only reported >450 μm size fraction.
[c] Analyzed for MP fibers only, majority less than 250 μm long.

172,000–519,000 particles m^{-3}, were several orders of magnitude larger due to the small sample sizes (300 mL) collected. In order to maintain more comparability in magnitude between the actual number of MP particles enumerated in samples and the density reported, we have standardized the data from bulk water samples in Table 1 to number L^{-1} instead of number m^{-3} thus reflecting actual sample size (<100 L) and allowing better comparison of the data between authors.

Data from bulk water grab samples have shown that there is a great deal of spatial variability in MP distribution in large lakes and rivers [24]. Therefore, many researchers have tried to collect larger sample volumes that are integrated over space and time to more accurately determine the MP concentration in these systems. Neuston nets, plankton nets, drift nets and manta trawls with mesh sizes ranging from 80 to over 333 μm have been suspended in rivers or towed from vessels for up to an hour (Table 2). Sample collection generally included the top 10–40 cm of the water column. The volume of water filtered (m^3) for each sample was calculated by multiplying the area (A) of the net mouth that was suspended in the water column by the distance (D) that the net was towed i.e. $V = A \times D$. For nets that were suspended in flowing water, sample volume was calculated by multiplying the net area by the flow rate (F) of the river (m/sec) and the time (T) the net was deployed (sec) i.e. $V = A \times F \times T$. Some authors attached flow meters to the mouths of the nets to more accurately determine the amount of water sampled, especially in instances where net clogging could occur. Sample volumes were much larger than those of bulk samples and ranged from 1.3 to 768 m^3 of surface water. Most authors [29–38] reported MP density as number of particles m^{-3} and found concentrations ranging from 0.05 to 223 m^{-3} (Table 2). A few authors [37,38] expressed their calculations as number of MP particles/1000 m^3 and reported

densities ranging from 317 to 4960 particles/1000 m^3. Since the actual sample sizes were generally less than 1000 m^3, we recommend that data on the concentration of MPs in surface water samples be reported as number m^{-3}.

Although many authors report the density of MPs collected from surface tows in lakes on a volumetric basis (number m^{-3}, Table 2), others have begun to report density on an areal basis (number m^{-2}, or number km^{-2}, Table 3) [12,24,33,35,38–46]. Sampling area is calculated by multiplying the width of the manta trawl or plankton net by the distance towed. The amount of raw data that is provided in the literature varies, and while some authors provide information on sampling area, we have had to estimate this value for some of the records in Table 3. Our calculations indicate that the surface areas that were sampled in those studies ranged from 16 to 2840 m^2. Even though the sampling areas are relatively small, many authors have been reporting the density of MPs as number km^{-2} (1,000,000 m^2) which leads to reported densities as high as 6,800,000 particles km^{-2} (Table 3). In reality, the actual number of MP particles in any individual sample is generally fairly low. For example, Mason et al. [43] found between 3 and 137 MP particles per sample in tows that covered approximately 1400 m^2. When density for these samples is calculated on the basis of a km^2, the reported values become 2138 to 100,016 particles km^{-2}. To better reflect the surface area sampled and the number of MPs actually found, we have standardized the data MP abundance in Table 3 to number/1000 m^2 instead of number/km^2.

2.3. Identification

There are more than 5000 types of synthetic polymers [11] used in plastic items, but 80% of the total plastic polymers are polypropylene (PP), polyethylene (PE), polyvinyl chloride (PVC),

Table 2
Data from net tows reported on a volumetric basis as MP particles m^{-3} or particles/1000 m^3.

Reference	Location	Collection method	Filtration mesh (μm)	Distance or time towed	Volume sampled (m^3)	Reported values
[30]	U.S. Great Lakes Tributaries	Neuston net, 100 × 40 cm, top 25–35 cm submerged	333	5–82 min,	6–768	0.05–32 m^{-3}
[31]	Seine River, Paris	Manta trawl top 30 cm submerged	330	15 min	182–200	0.28–0.47 m^{-3}
[31]	Seine and Marne Rivers, Paris	Plankton net, top 10–35 cm submerged	80	1 min	0.43–2.0	4–108 m^{-3}
[32]	Raritan River New Jersey	Plankton net, 20 cm diameter, half submerged	153	1 h	1.3–3.5	24–7.7 m^{-3}
[33]	Swiss Rivers	Manta 60 × 18 cm	300	15–30 min	NR	7 m^{-3}
[34]	Lakes Bolsena and Chiusi, Italy	Manta 60 × 18.5 cm	300	1 h, 3861–4983 m	[a]429–533	0.82–4.41 m^{-3}
[29]	Saigon River and canals, Vietnam	Plankton net	300	1 min	NR	10–223 m^{-3}
[35]	North Shore Channel, Chicago	Neuston nets, 92 × 42 and 36 × 41 cm	333	20 min	NR	1.94–17.93 m^{-3}
[36]	Los Angeles and San Gabriel Rivers	Manta 90 × 15 cm	333	Up to 15 min	NR	<1–153 m^{-3}
[37]	Danube	Drift net, 50 cm diameter	500	30 min	NR	317/1000 m^3
[38]	Rhine River	Manta, 60 × 18 cm	300	15 min	60–250	4960/1000 m^3

[a] Volume filtered was calculated by authors from the area of net mouth and reported distance towed.

Table 3
Data from net tows reported on an areal basis as MP particles/unit area (m^2 or km^2).

Reference	Location	Collection method	Filtration mesh (µm)	Distance or time towed	Area sampled (m^2)	Reported values (particles/km^{-2})	Standardized (particles/1000 m^2)
[39]	Lake Winnipeg	Manta trawl, 61 × 18 cm	333	530–3780 m, 8–30 min	[a]323–2306	52,500–748,000	52.5–748
[12]	Laurentian Great Lakes	Manta trawl 61 × 16 cm	333	1940–4000 m, 60 min	[a]1183–2440	450–466,000	0.45–466
[40]	Lake Geneva	Manta trawl	300	3700 m	2222	48,146	48
[33]	Swiss Lakes and Rivers	Manta trawl 60 × 18 cm	300	3000–4000 m	320–430	91,000	91
[41]	Lake Hovsgol, Mongolia	Manta trawl 61 × 16 cm	333	3100–4100 m, 1 h	[a]1890–2500	997–44,435	1–44
[42]	Lake Superior	Manta trawl 85 × 14 cm	333	500–2000 m	[a]425–1700	0–110,000	0–110
[43]	Lake Michigan	Manta trawl 61 × 16 cm	333	1540–4660 m, 30 min	[a]939–2840	0–100,000	0–100
[38]	Rhine River	Manta trawl 60 × 18 cm	300	15 min	NR	892,777	893
[35]	North Shore Channel, Chicago	Neuston nets, 92 × 42 and 36 × 41 cm	333	20 min	NR	730,000–6,700,000	730–6700
[44]	Lakes Maggiore, Gada and Iseo, Italy	Manta trawl 60 × 20 cm	300	[b]2000 m	[b]1200 m^2	4000–57,000	4–57
[24]	Taihu Lake, China	Plankton net, 65 cm diam. Top 30 cm	333	25–2500 m, 1–30 min	[a]16–1600	10,000–6,800,000	10–6800
[45]	Qinghai Lake	Manta trawl 100 × 50 cm	112	2000 m	NR	5000–758,000	5–758
[45]	Four tributaries to Qinghai Lake, China	Manta trawl 100 × 50 cm	112	10–20 min	NR	3000–31,000	3–31
[46]	Three Gorges Reservoir and tributaries, China	Manta trawl 100 × 50 cm	112	400 m	[a]400	192,000–13,600,000	192–13,600

[a] Calculated from trawl width and distance towed reported in the paper.
[b] Calculated from net dimensions and average volume filtered.

polyethylene terephthalate (PET) and polystyrene (PS) [1]. As plastic debris is found in smaller micro to nano-particle sizes, it becomes more challenging to distinguish the plastic particles from natural debris using microscopes. However, it is imperative to do positive identification of plastic particles to avoid overestimation. It is commonly known that it is almost impossible to analyze all the MP particles in a large sample (Fig. 2), but it is necessary to analyze a certain proportion of the total particles. There are several techniques that have been proposed to identify synthetic polymers (Table 4).

Spectroscopy is an excellent technique used to positively identify the synthetic polymers in a sample. Attenuated Total Reflectance with micro-Fourier Transform Infrared (ATR-µFT-IR)

Fig. 2. Microplastics (mainly fibers) from effluent water (Wastewater Treatment Plant-Two Harbors, MN).

spectroscopy improves the spatial resolution with the combination of microscopy. This technique is one of the most reliable techniques, producing high quality spectra and the sample does not need chemical preparation prior to analysis. However, the analysis is time consuming so researchers have generally only analyzed a portion of the suspended MP particles from each sample (Table 4). In addition, Focal Plane Array with FT-IR can be used but requires chemical sample preparation, e.g. 30% hydrogen peroxide as pretreatment to eliminate biogenic material that can interfere in the analysis of MPs [47]. The use of µRAMAN spectroscopy is also recommended, but this method has interference from pigment spectra. Pyrolisys-Gas Chromathography coupled to Mass Spectrometry (GC/MS) uses thermal degradation of microplastics for its analysis [20,42] and is therefore destructive of the sample material. There are other techniques that are currently used to confirm in a qualitative way the microplastics presence in samples, such as Scanning electron microscopy (SEM) [12,24,38,43]. SEM obtains high resolution images that can be combined with other instrumentation such as energy dispersive spectroscopy (SEM-EDS) or energy dispersive X-ray spectroscopy (SEM-XEDS), to measure the diffraction and reflection of emitted radiation from particle surfaces, thus providing information on the chemical and morphological characterization of particles. While these techniques produce elemental analysis, they are just doing qualitative analysis identifying particles that are similar to plastic, but they are not confirmatory tests, therefore it is easy to misinterpret the identification of MPs. Semiqualitative analysis methods can also be used to identify MP particles including Coulter counters (conductivity), stains such as Nile Red dye [48,49], and visual sorting [30–32,35–37,40,41]. Smaller sized MPs, from 10 µm to nanosizes can be easily confused with natural debris such as cellulose and wood, with cellophane and rayon, or with coal ash, glass, and sand. Several authors [12,24,25,28,32,39] have shown that non-plastic materials can often comprise 20–40% of the particles initially sorted as MPs (Table 4).

Table 4
Methods used for identification of MP particles in surface water samples and possible effects on density estimates.

Type of analysis	Identification method used	Number of particles or % sample used for confirmation	Density of non-plastic materials	Reference
Quantitative	μRaman/SEM	87 particles	21%	[28]
Quantitative	FTIR	2 particles from each sample, different size/shape categories- 44 total	All were plastic	[26]
Quantitative	FTIR	118 of 25,956 or 0.45%	13.6% not assigned to any specific polymer, spectra indicated plastic additives	[38]
Quantitative	FTIR	50 to 100 particles from each site	Spherical aluminum silicate particles, reflect light differently than plastics, confirmed by SEM/EDS	[46]
Quantitative	Visual/FTIR	10% of total or 206 of larger micro-plastics	2% of total	[33]
Quantitative	FTIR	57 fragments−15% of total	8.8% not plastic	[29]
Quantitative	FTIR	76 fibers − 10% of total	5% natural	[29]
Quantitative/qualitative	SWIR	524 particles validated	25% false positives	[25]
Quantitative/qualitative	FTIR, SEM/EDS	113 particles (6% of total)	28% (32 particles) were not plastic	[24]
Qualitative	SEM/EDS	8 to 32 particles/sample for 9 samples from 2014	23% were silicates, iron oxide, or paint flakes	[39]
Quantitative/qualitative	SEM/EDS Or FTIR	SEM of all of the small particles from 20% of sites with 355−999 μm particles. FTIR of 59% (72) particles > 4.75 mm	16% of small size class was mineral material by SEM. 8% of larger particles unknown composition by FTIR	[43]
Qualitative	Nile red stain/UV microscope SEM of few fibers	20 fibers	40% of fibers were cotton	[34]
Qualitative	SEM/EDS on smallest size class	All items < 1 mm	8 samples had average of 20% aluminum silicates	[12]

3. Discussion

Our literature review demonstrates that scientists have used a variety of methods to collect MP samples from freshwater lakes and rivers with sample volumes ranging from 300 mL to 800 m^3 while sampling surface areas of 16−3000 m^2. MP densities have been reported in many different units including particles L^{-1}, particles m^{-3}, particle/1000 m^3, particles/1000 m^2, and particles km^{-2}. Some of the MP concentrations that were reported were quite large, i.e. 519,000 particles m^{-3} [29] or 13,600,000 particles km^{-2} [46]. While these density calculations are accurate, they over represent the actual sample sizes (300 mL and 400 m^2 respectively) and to a casual reader imply that the authors encountered thousands of MP particles in each of their samples. Although the actual number of MPs in each sample is generally quite low, the calculated density values increase exponentially as data is converted to large sampling volumes or areas. For example, if 30 MP particles are found in a 300 mL bulk water sample, an author could accurately report this density as 100 particles L^{-1} or 100,000 m^{-3}. If 30 MP particles were discovered in a sample collected with a 60 × 16 cm manta trawl that was towed for 1000 m, the sample volume would be 96 m^3 and the sampling area would be 600 m^2. MP density in this sample could then be reported as 0.31 particles m^{-3}, 310/1000 m^3, 0.05 m^{-2}, 50/1000 m^2 or 50,000 km^{-2}.

While scientists often prefer to report data in whole numbers rather than in decimal fractions, MP densities should be reported in units that reflect actual sample size. Therefore, density of MPs in bulk water samples should be reported as number L^{-1} instead of number m^{-3} because actual sample sizes are generally less than 100 L. When MPs are sampled with nets that filter several hundred cubic meter of water, density can be reported as number m^{-3} or number/1000 m^3. If the density of MPs from nets samples is to be expressed on an areal rather than a volumetric basis, these values should be reported as number/1000 m^2, and not as number km^{-2}, due to the fact that the sampling area is generally only a few thousand m^2 in size.

If a robust sampling design is used to collect a large number of representative samples distributed across a water body, the data can then be used to estimate the average density of MPs in the system based on a large area (km^2) [38,43,50]. The average density of MPs in Lake Michigan has been estimated as 17,000 particles km^{-2} [43] and the Rhine River has been reported to contain 893,000 particles km^{-2} [38].

Details on the methodology used for the analysis and calculation of MP abundance are critical when comparing data between studies. Authors should provide basic information on sample size, number of samples, and amount of sample examined. It is also important for authors to provide enough raw data in their reports or appendixes so that others can calculate MP densities in different ways and enable more comparisons. By knowing the width and depth of the mouth of manta trawls, as well as the distance towed for each sample, data can be reported on both a volumetric and an areal basis. The use of flow meters to determine distance towed or volume filtered is recommended to account for net clogging and water currents.

While the definition of MPs includes all particles between 100 nm and 5 mm, most authors only include data on a small fraction of this size range due to limitations with collection and analysis of the smaller particles. Reporting the mesh size used for collecting and processing samples as well as the size distribution of particles in each sample allows authors to compare their data with others who may have reported only large sized particles. Information on the concentration of each size and type of MPs in water samples is also important when performing risk assessments and designing lab experiments which try to mimic the actual concentrations of MPs found in nature.

Another important factor that contributes to variation in reported MP concentrations is the processes that are used for identification of MPs (qualitative or quantitative). Visual sorting of MPs should be followed by a more detailed analysis to determine the composition of the particles. This is necessary to avoid the overestimation of MPs based on counting all particles that seem to resemble plastics (e.g. cotton vs polyester fibers). Errors can increase during qualitative analyses of small particles with sizes close to nanoparticles (e.g.Lahens [29]). We recommend that all plastic-like particles in small samples (<100 particles) be identified and that subsamples consisting of 10−20% of the total number of particles be selected for analysis from each large sample.

MPs occurs in a variety of forms and are generally classified as fragments, films, lines, spheres, filaments, sheets, pellets,

microbeads, fishing lines, ropes, foams, or fibers. Because fibers are found in much higher densities than the other MPs in freshwater environments, we suggest that MP fibers be enumerated and analyzed separately from the other forms of MPs. When MP fibers are entangled, they are very difficult to sort and analyze. We suggest that fibers should initially be visually sorted into groups by color and similar appearance. Three or four similar fibers from each group should be selected for analysis of plastic composition. If they are all identified as the same synthetic polymer, then one can assume than the rest of the fibers in the group are the same material, for this set of samples. Conversely, if the analysis shows more than one type of polymer, then more analysis needs to be done.

4. Conclusion

The presence of MP debris in aquatic ecosystems is a very real and tangible environmental issue and there is no reason to sensationalize the matter by reporting MP densities in units that produce extremely large numbers in order to attract the attention of the scientific community, policymakers, industry, or the general public. Scientists should select sampling methods that are best suited to their goals, i.e. use bulk water samples for detailed analyses of very small size MP particles and employ larger mesh nets to collect greater sample volumes. In all cases, the density of MP particles should be reported in units that are comparable to the original sample size. We recommended that the density of MPs from bulk samples be reported as number L^{-1} instead of number m3, and densities from net samples be reported as number m^{-3}. If the density of MPs from net samples is to be expressed on an areal basis, values should be reported as number/1000 m^2, and not as number km^{-2}.

The collection and analysis of MP particles from lakes and rivers is very time intensive and expensive. Few authors have sampled multiple sites or multiple times of the years to come up with accurate aquatic system estimates of MP concentrations. Care should be taken when extrapolating data from a few samples to entire lakewide concentrations.

It is very difficult to distinguish small MPs from natural debris using just microscopy. Spectroscopy (ATR-µFT-IR and µRAMAN) and Pyrolysis-Gas Chromatography coupled to Mass Spectrometry are techniques that could be used to quantitatively identify the polymers in MP particles.

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