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1 **Microplastic and microfiber fluxes in the Seine River: Flood events versus Dry periods**

2

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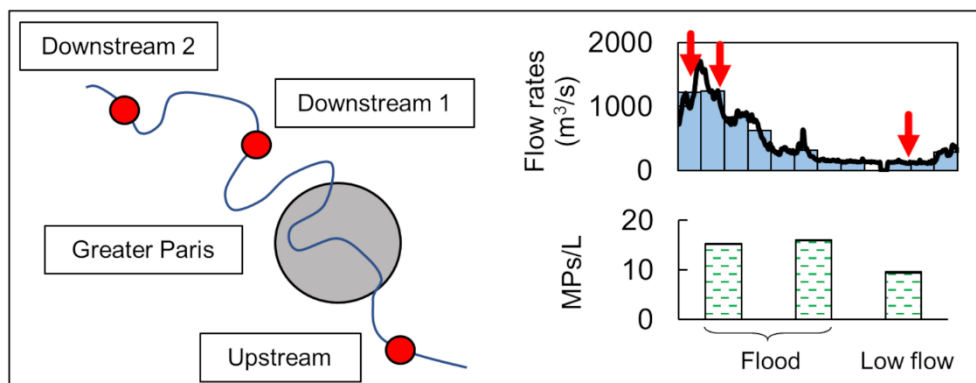
11 Abstract

12 Studies on the influence of hydrodynamic conditions on anthropogenic microfiber (MF) and
13 microplastic (MP) distributions in freshwater environments are sparse. In this study, we
14 studied the influence of urbanisation gradient on the spatial variability of MFs and MPs.
15 Temporal variability was also assessed by comparing the concentrations and fluxes of MFs
16 and MPs under low flow conditions with those during the January-February 2018 flood event.
17 For each period, Seine river water was collected upstream and downstream of Greater Paris
18 and filtered through an 80 µm net at three different sampling sites. MFs were counted using
19 a stereomicroscope, while MPs were analysed using micro-Fourier transform infrared
20 spectroscopy coupled with siMPle analysis software. The highest concentrations of MFs and
21 MPs were reported at the furthest downstream sites during both periods. However, high
22 water flowrates and urbanisation gradient did not significantly impact MF and MP
23 concentrations, sizes, or polymer distributions. The median MF and MP concentrations were
24 2.6 and 15.5 items/L and their interquartile ranges were 1.6 and 4.9 items/L (n=10),

25 respectively, illustrating relatively stable concentrations in spite of the urbanisation gradient
26 and variations in the flowrate. In contrast to the concentration, size, and polymer distribution
27 characteristics, MP mass fluxes were strongly affected by river flow. MF and MP fluxes show
28 increases in the number and mass of particles from upstream to downstream. The
29 downstream site presents high MP mass fluxes, which range between 924 and 1675
30 tonnes/year. These results may indicate significant MP inputs from the Paris Megacity
31 through wastewater treatment plant effluents and untreated stormwater. The January-
32 February 2018 flood event, which represented 14.5% of the year (in terms of time),
33 contributed 40% of the yearly MP mass fluxes. Thus, flood events contribute strongly to MP
34 fluxes.

35 KEYWORDS: microplastic, microfiber, microlitter, plastic pollution, flood, hydrological
36 conditions

37 Graphical abstract



38

39 1. Introduction

40 Microlitter, such as microfibers (MFs) and microplastics (MPs), represent a threat to marine
41 (Cole et al., 2011; Gall and Thompson, 2015; Jamieson A. J. et al., 2019) and freshwater
42 environments (Blettler et al., 2017). An increasing number of studies have investigated the
43 transport of microlitter in freshwater environments. The development of microlitter analysis in
44 environmental matrices such as surface waters (Horton et al., 2017) and sediments (Klein et
45 al., 2015) has led to significant advances in assessing the concentration of these particles.

46 However, very few studies have been conducted on the influence of hydrological conditions
47 and urbanisation gradients on microlitter concentrations in rivers.

48 Several studies have observed higher concentrations of microlitter during low-flow periods
49 than in high-flow conditions (de Carvalho et al., 2021; Rodrigues et al., 2018; Watkins et al.,
50 2019; Wu et al., 2020). This difference in concentrations was attributed to a dilution effect.

51 Other studies did not observe significant differences in microlitter concentrations between
52 low and high-flow conditions (Schmidt et al., 2018; Wagner et al., 2019). According to these
53 studies, other parameters may influence the microlitter concentrations. Several studies did
54 not evaluate variation linked to flowrate seasonality, but focused on the impact of rain events
55 during low-flow conditions. Hitchcock (2020) showed that under low-flow conditions, the MP
56 concentration of a small urban estuary river increased during two days of heavy rain, from
57 400 particles/m³ to 17 000 particles/m³. Wong et al. (2020) observed a correlation between
58 MP concentrations and precipitation in freshwater environments and noted a strong impact
59 of runoff on MP distribution. Rain events may increase the MP input in rivers owing to the
60 leaching of soil and sealed surfaces. Rain events can lead to combined sewer overflows and
61 untreated stormwater discharge to rivers (Blettler et al., 2017). Thus, rain events may induce
62 a flushing effect, that is, an increase in the MP input to freshwater resulting from
63 mismanaged urban water (Schmidt et al., 2018). Other studies have suggested that there is
64 no simple correlation between river flow and MP concentration (Kataoka et al., 2019;
65 Wagner et al., 2019). Kataoka et al. (2019) observed a correlation between MP
66 concentrations and water quality, but no relationship between MP concentrations and
67 flowrates. Other studies have shown that flood events may play a key role in plastic debris
68 loads in rivers (Roebroek et al., 2021; Tramoy et al., 2020b). Veerasingam et al. (2016)
69 observed a significant increase in MP pellet concentrations in beach sediments after a flood
70 event. These pellets may have been remobilised and more easily migrated from land to sea.
71 Hurley et al. (2018) showed that a significant amount of the MP load stored in channel-bed
72 sediments was exported after a flood. According to these studies, MPs may be efficiently

73 flushed from the river to the sea during a flood. Anthropogenic MFs are rarely considered in
74 these studies, even though they are ubiquitous contaminants (Zhao et al., 2016). Thus, the
75 relationship between microlitter concentration, flow rates, and precipitation is still debated.

76 Several studies concerning the influence of the urbanisation gradient have observed higher
77 MP concentrations in urbanised, densely populated, and downstream areas (Kataoka et al.,
78 2019; Schmidt et al., 2018; Wagner et al., 2019; Wu et al., 2020). In several of these studies,
79 MP concentrations were correlated with population density (Kataoka et al., 2019; Wu et al.,
80 2020). According to Wagner et al. (2019), plastic concentrations may be constant in rural
81 areas but increase linearly in urban areas owing to inputs associated with urban discharge
82 during rainy weather. Rodrigues et al. (2018) observed higher concentrations upstream of
83 the catchment studied. This observation may be a particular to the sampling site, as the
84 upstream part of the catchment studied has a higher population density (Rodrigues et al.,
85 2018). However, Wong et al. (2020) observed no correlation between MP concentrations
86 and population density. Thus, various conclusions may be drawn, depending on the
87 sampling site.

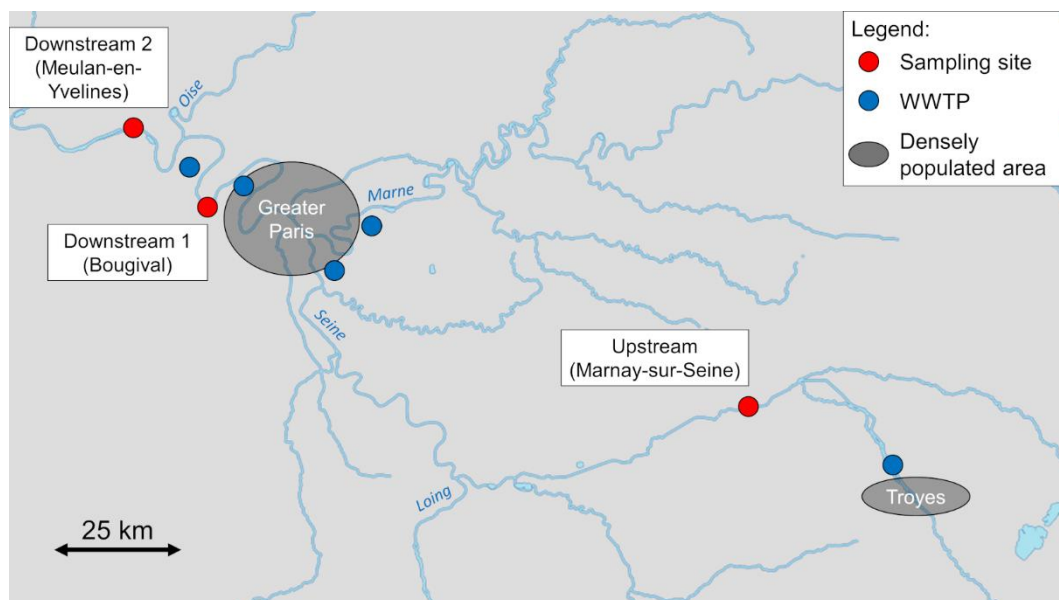
88 In this study, MF and MP concentrations were estimated at three different sampling sites
89 upstream and downstream from Greater Paris during low flow conditions, as well as during a
90 flood event that occurred in January-February 2018. The main objectives of this work were
91 to evaluate the influence of the urbanisation gradient and different hydrological conditions on
92 the MF and MP concentrations and fluxes.

93 2. Materials and methods

94 2.1. Sampling sites

95 Three sampling sites were selected: (i) the first site, noted "Upstream", is located 100 km
96 upstream of Paris (Greater Paris, 8.9 million capita, 2 546 km², 3 700 cap/km²) and
97 downstream of the moderately dense city of Troyes (Troyes Champagne Metropolis,
98 170 167 capita, 889 km², 191 cap/km², with a waste water treatment plant capacity of 260

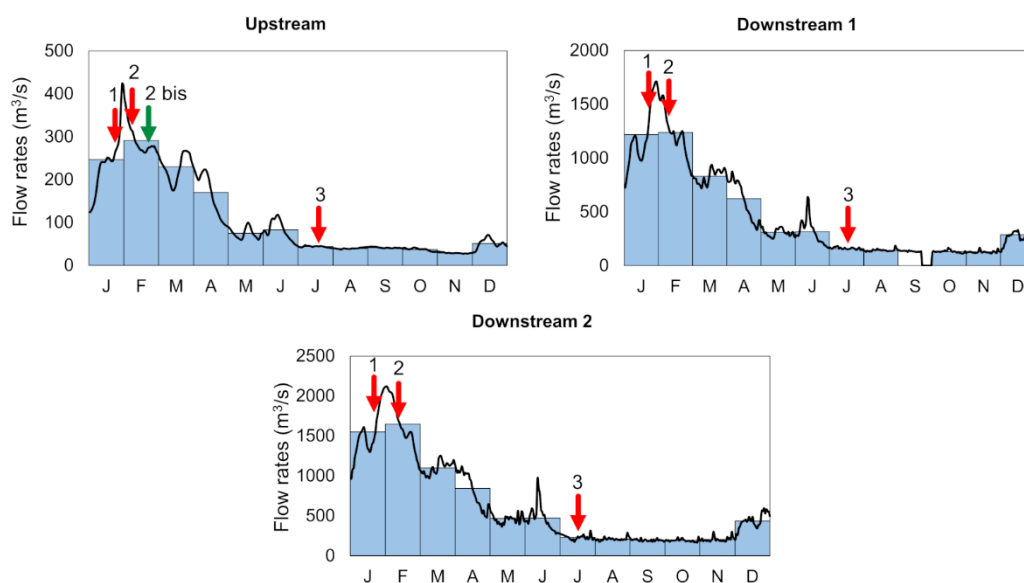
99 000 population equivalent) ; (ii) the two other sites are located 20 and 45 km downstream of
 100 Paris and noted as “Downstream 1” and “Downstream 2”, respectively. Upstream is less
 101 impacted by industrial activities, whereas Downstream 1 and 2 correspond to a dense
 102 urbanised area. Downstream 1 is located downstream from three significant waste water
 103 treatment plants (noted as WWTP, “Seine Centre”, “Seine Amont” and “Marne Aval”, which
 104 have treatment capacities of 240 000, 600 000 and 75 000 m³ per day, respectively),
 105 Downstream 2 is located downstream of the most significant WWTP of Paris Megacity
 106 (Seine Aval, which has a treatment capacity of 1 700 000 m³ per day, according to the
 107 Parisian Public Sanitation Authority) and is also located downstream of the confluence
 108 between the Seine River and Oise River, which is one of its main tributaries (Figure 1). The
 109 major potential sources of microplastics are: (i) Combined Sewer Overflows (CSO) of
 110 Greater Paris, (ii) Waste Water Treatment Plants (treatment capacity > 75 000 m³ per day),
 111 (iii) untreated stormwater, and (iv) densely populated areas with intense industrial activities
 112 near the different sampling sites.



113
 114 Figure 1: Location of the sampling sites, most significant Wastewater Treatment Plants
 115 (WWTPs, treatment capacity > 75 000 m³ per day) and densely populated areas (the
 116 hydrographic network is from Geoportail France).

117 2.2. Sampling method

118 Three sampling campaigns were performed during contrasting hydrological conditions: two
119 campaigns were conducted during the flood event that occurred in January-February 2018,
120 represented by the numbers 1 and 2 in Figure 2 (01/26/18 and 02/21/18, $Q_{\max \text{ Paris}} = 1710$
121 m^3/s , with a 10 year return period of $Q_{10} = 1650 \text{ m}^3/\text{s}$ and a 100 year return period of $Q_{100} =$
122 $2400 \text{ m}^3/\text{s}$) and one campaign was conducted during the dry season during a low water level
123 period, represented by the number 3 in Figure 2 (07/17/18, $Q_{\text{Paris}} = 155 \text{ m}^3/\text{s}$). The Seine
124 River was monitored by a surveillance network that followed the flow variations (Figure 2).
125 Samples were collected at each site during the same day in the following order: Upstream,
126 Downstream 1, and Downstream 2. One extra sample was collected on 02/21/18 from the
127 Upstream sampling site (2 bis, green arrow in Figure 2). The first campaign (01/26/18)
128 corresponded to a period of increasing flow just before the flow peak. The following
129 campaign in February 2018 corresponded to a decrease in the water flowrate. The daily
130 flowrates and water levels of each sampling campaign are presented in the supplementary
131 data (Table S1). Between 20 and 30 L of water were manually collected from the bridges
132 using a metal bucket and filtered through an 80 μm net. Plastic materials were banned to
133 avoid any on-site contamination. The net was systematically rinsed before and after
134 sampling. The samples were then stored in glass containers in a cold room (4°C).



135

136 Figure 2: Daily flowrates (black lines) and monthly mean flowrate (blue bars) of the different
 137 sampling sites for 2018. Date of sampling is represented by the red arrows (data from
 138 <http://hydro.eaufrance.fr>, Upstream, Downstream 1 and Downstream 2 flowrates were
 139 assessed using Pont-sur-Seine, Austerlitz and Vernon measurements, respectively). The
 140 green arrow indicate the extra sample collected at the Upstream sampling site.

141 2.3. Analytical procedure

142 Samples were sieved using a 5 mm and a 1 mm sieve and separated into the 1-5 mm
 143 fraction and <1 mm fraction. Sieving did not prevent the entrance of long fibers (> 5 mm) in
 144 the <1 mm fraction, owing to their small diametres. Particles in the 1-5 mm fractions were
 145 inspected under a stereomicroscope. Based on their colour, shape, and texture, suspected
 146 plastic particles were set aside and characterised using infrared spectroscopy with
 147 attenuated total reflectance (ATR-FTIR, Thermo Scientific™ iD7 accessory). This method is
 148 based on Dris et al., 2017. For the <1 mm fraction, organic matter was oxidised using 30
 149 wt% H₂O₂ digestion at 40°C for 48 h with 50 mL of solution and magnetic stirring (300 rpm).
 150 Digestion was conducted at temperatures ≤ 40°C to avoid thermal degradation of the MFs
 151 (Treilles et al., 2020). The solution was filtered through a metallic filter (Ø = 90 mm, porosity
 152 = 14 µm). MP particles were then separated from mineral matter by densimetric separation

153 in a NaI solution ($\rho \geq 1.6 \text{ g.cm}^{-3}$) in a separating funnel. The supernatant was filtered using
154 the same metallic filters and the microlitter was characterised.

155 Because of their shapes, the automatization of MF detection with μFTIR and processing
156 software cannot be implemented confidently. Indeed, confusions between MFs and MP
157 fragments were frequently observed with automated μFTIR detection. For this reason, all
158 MFs were manually counted under a stereomicroscope (Leica MZ12, with a size detection
159 limit of $50 \mu\text{m}$) coupled with an image analysis software (Histolab) according to the method
160 developed by Dris et al. (2018), while MPs were counted and chemically characterized by
161 μFTIR imaging, with no shape distinction. MFs are all anthropogenic fibers, including
162 synthetic and non-synthetic fibers. This results in possible crossed data between MFs and
163 MPs. However, we decided to keep the data in this form, as the size distribution between
164 MPs and MFs is significantly different (Figure 5). Indeed, most of MPs are below $250 \mu\text{m}$
165 whereas MFs are above $1000 \mu\text{m}$ (Figure 5). This overlap of data may thus be negligible.

166 Once the MFs were counted, metallic filters were plunged in a crystallizer with 20 mL of
167 filtered water and the particles were removed using an ultrasonic bath for 30 s. The filtered
168 water was then poured into a 100 mL glass bottle. This resuspension step was repeated
169 three times. Then, the metallic filter was rinsed one last time with 40 mL of filtered water.

170 The glass bottle was vigorously stirred for 1 min to homogenise the content. Then, 10 to 20
171 mL of this volume, *i.e.*, 10 to 20 %, was filtered onto a Whatman® anodisc inorganic filter
172 membrane (porosity: $0.2 \mu\text{m}$, $\varnothing 25 \text{ mm}$, with a filtration surface of $\varnothing 14 \text{ mm}$).

173 The anodisc filters were analysed with Fourier transform infrared spectroscopy coupled with
174 a microscope, using the Thermo Scientific Nicolet™ iN10 μFTIR in transmission mode. A
175 Thermo Scientific® MCT/A Cooled Imaging detector with a spectral range of 4000 to
176 1200 cm^{-1} was used to avoid interference with the anodisc filter. An autobaseline correction
177 was applied to all spectra. After the spectral background was defined, the mapping analysis
178 mode was used on one scan. All particles on three $6 \times 6 \text{ mm}$ infrared maps were analysed,
179 corresponding to 70% of the filtration surface of the filter. An atmospheric suppression
180 correction was applied to all spectra. Maps were analysed using the siMPle analysis

181 software developed by Aalborg University, Denmark and the Alfred Wegener Institute,
182 Germany (Liu et al., 2019).
183 This method has a size detection limit of 25 μm . Each spectrum identified as a plastic
184 polymer by the siMPle software was checked by an operator for false positives. Particular
185 attention was paid to PE spectra, as false positives of these particles have been observed in
186 other studies (Witzig et al., 2020). siMPle assesses the number of particles and estimates an
187 order of magnitude for the mass and volume of MPs, as detailed in Kirstein et al., 2021. MP
188 concentrations were extrapolated to the initial sampling volumes. Because the number of
189 samples remained small, non-parametric statistics were used in the analysis.
190 Several precautions were applied to mitigate contamination. Glass vessels and filters were
191 all heated to 500°C for 2 h before use. All solutions used were filtered on GF/D Whatman
192 glass fibre filters (Sigma Aldrich, porosity: 2.7 μm). The vessels were rinsed with filtered
193 water and filtered using 50% ethanol. Laboratory coats of 100% cotton were worn and
194 plastic materials were avoided. The samples were stored in glass bottles. Glass bottles and
195 all beakers were covered with aluminium foil. The samples were sieved using a laminar flow
196 cabinet. Contamination during the different extraction steps was evaluated using procedural
197 blanks (n=10), which underwent the same steps as the samples.

198 3. Results and discussion

199 3.1. Microfiber and microplastic concentrations

200 During the flood event, MF concentrations ranged between 1.3 and 3.7 items/L, whereas MP
201 concentrations ranged from 10.4 to 34.4 items/L (Figure 3). In low flow conditions, MF
202 concentrations ranged from 1.9 to 5.5 items/L, whereas MP concentrations ranged from 9.3
203 to 26.5 items/L (min–max values). Median MF contamination was 0.3 items/L with an
204 interquartile range of 0.2 (n=10) whereas median MP contamination was 0.2 items/L with an
205 interquartile range of 0.2 (Figure 3).

206 Variations in the minimum and maximum concentrations of all samples were calculated for
207 each sampling site, under low flow conditions and during the flood (variation in concentration

208 = (Max-Min)/Min) * 100) (Table 1). Upstream and Downstream 1 presented relatively low
 209 variations between the minimum and maximum concentrations for both MFs (< 25%) and
 210 MPs (<71%) (Table 1). Downstream 2 presented the highest MF (229.8%) and MP
 211 concentrations (318.0%) (Figure 3) and the highest variability between minimum and
 212 maximum values (Table 1).

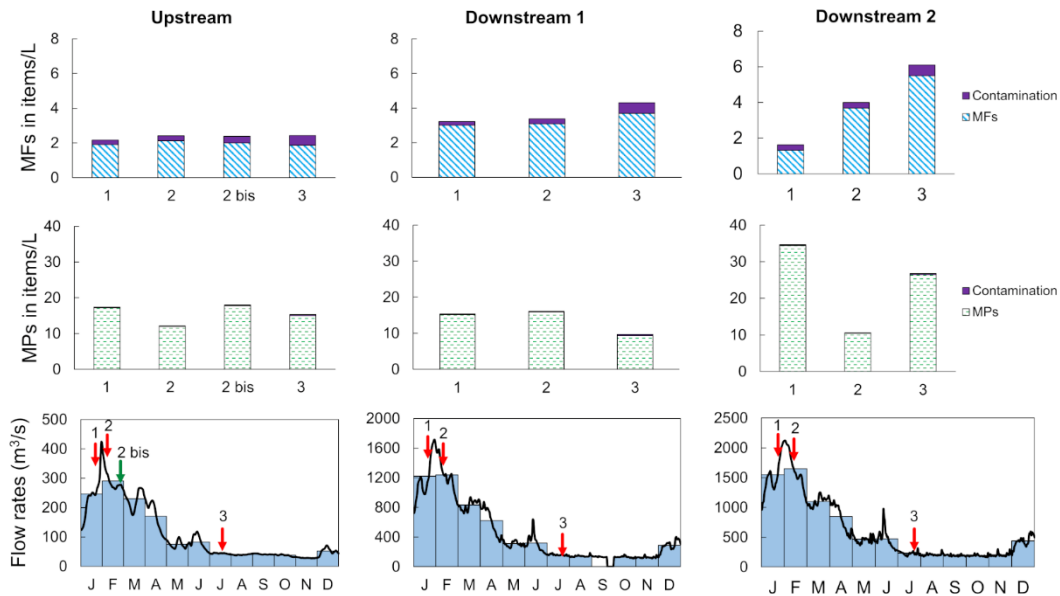
213 Table 1: Variation in concentrations between minimum and maximum values for each
 214 sampling site, for samples collected in low flow conditions and during the flood

	%Variation between min-max values for MFs	%Variation between min-max values for MPs
Upstream	14.4	49.0
Downstream 1	23.3	70.3
Downstream 2	318.0	229.8

215

216 If all samples are combined, we obtain MF and MP median concentrations of 2.6 and 15.5
 217 items/L and interquartile ranges of 1.6 and 4.9 items/L, respectively (n = 10). Other studies
 218 in freshwater environments generally have found concentrations below 1 items/L (de
 219 Carvalho et al., 2021; Kataoka et al., 2019; Wong et al., 2020). The concentrations we found
 220 are comparable to those found in Cooks River, Australia (between 0.4 and 17.4 items/L,
 221 Hitchcock, 2020) and in the Maozhou River, China (between 3.5 and 25.5 items/L, Wu et al.,
 222 2020). We found that MPs were more abundant than MFs. Several studies have also
 223 reported fewer fibers than other shapes in freshwater samples (Mani and Burkhardt-Holm,
 224 2020; Mao et al., 2020; Wu et al., 2020). Stereomicroscope counting did not enable the
 225 detection of MFs below 50 µm. Therefore, we may have underestimated the MF
 226 concentration. Despite a strong urban gradient and high water flow variability between
 227 sampling sites, MF and MP concentrations during low flow conditions have the same order
 228 of magnitude as the concentrations estimated during the flood event of January-February

229 2018 (Figure 3 and Table 1). Downstream 2 presented the highest variability (Table 1) and
230 the highest concentrations (Figure 3) of MPs and MFs, both during low-flow conditions and
231 the flood event. This may indicate a significant release of MPs related to WWTPs. However,
232 Downstream 2 is located downstream the confluence with the Oise River (Figure 1), which
233 was also flooded. This tributary is less urbanised and may dilute the microlitter inputs at this
234 sampling site. However, the flood event did not significantly change the concentrations
235 observed at the different sampling sites. As previously noted, contradictory results were
236 found regarding the influence of water levels and flows on MP concentrations. The dilution of
237 MPs during flood events has been reported in several studies (Rodrigues et al., 2018;
238 Watkins et al., 2019; Wu et al., 2020), but does not seem to occur in the Seine River. Recent
239 studies have shown that stormwater runoff could be a significant source of macroplastics
240 (Treilles et al., 2021b) and microplastics during rain events (C. Liu et al., 2019; Treilles et al.,
241 2021a). Precipitation may increase microlitter inputs through stormwater runoff. The increase
242 in the flowrate during a flood implies remobilisation of the sediments owing to an increase in
243 the shear strength, as well as remobilisation of MF and MP stored in sediments (Hurley et
244 al., 2018). However, in the Seine River, waterway traffic may greatly influence this
245 distribution. In 2019, 23.7 millions of tons of goods were transported by waterway traffic in
246 the Seine River basin (Voies Navigables de France, 2020). This intense activity influences
247 the sediment dynamics, which are not in a steady state (Vilmin, 2014). Waterway traffic
248 intensively remobilises sediments even under low-flow conditions. This could partially
249 explain the similar values observed between the flood and low-flow conditions. To ensure
250 better comparability between studies, waterway traffic and sediment dynamics in a study
251 area should be precisely recorded. The concentrations found in the Seine River are very
252 high compared to those presented in a previous study on this river ($\sim 3 \times 10^{-4}$ MPs/L ; Dris et
253 al., 2015). The Seine River concentrations are also high compared to those found in the
254 Rhine ($\sim 1 \times 10^{-3}$ – 3×10^{-3} MPs/L ; Mani et al., 2015). Contrary to Wong et al. (2020), we found no
255 statistically significant correlations between precipitation and concentration (Spearman's r_s
256 test, $p = 0.89$).



257

258 Figure 3: Microfiber and microplastic concentrations in the Seine river, relative to the
 259 hydrograph of each site (y-axis are different depending on the sampling site)

260 Regarding the spatial variations, concentrations between the upstream and downstream
 261 areas were of the same order of magnitude. This is consistent with previous data collected
 262 by Dris et al. (2018), who did not notice a significant impact of the urban gradient or
 263 variations in the flow rate on the MF or MP concentrations in the Seine River. These
 264 observations were confirmed by the present study at a larger scale. Based on the size and
 265 shape of the particles, the siMPle analysis software enables MP mass concentration
 266 estimates. However, it was not possible to estimate the mass of the MFs that we counted
 267 using a stereomicroscope. The order of magnitude for MP mass concentrations was
 268 comparable between the low flow period and the flood event, as shown in Table 2. We did
 269 not observe a significant concentration gradient between the upstream and downstream
 270 sites of Greater Paris in terms of mass concentrations, which is consistent with the results of
 271 Dris et al. (2018). In addition, Downstream 2 presented the highest mass concentrations in
 272 number of particles (Table 2). MP mass concentrations in freshwater environments have
 273 been only rarely estimated. Using the total weight/number of microplastics and non-metric
 274 multidimensional scaling (nMDS), Rodrigues et al., 2018 reported mass concentrations
 275 between 5 and 51.7 $\mu\text{g/L}$ in Antuã River, Portugal. These values were comparable to our

276 estimations. Several studies have reported lower mass concentrations. In surface water
277 samples, Haberstroh et al. (2021) found a mean mass concentration of 5.4 µg/L in the
278 Hillsborough River, USA. Kataoka et al. (2019) observed variable MP mass concentrations
279 between 0 and 3.2 µg/L.

280 Table 2: Estimation of MP mass concentrations in Seine River water based on siMPle
281 software analysis.

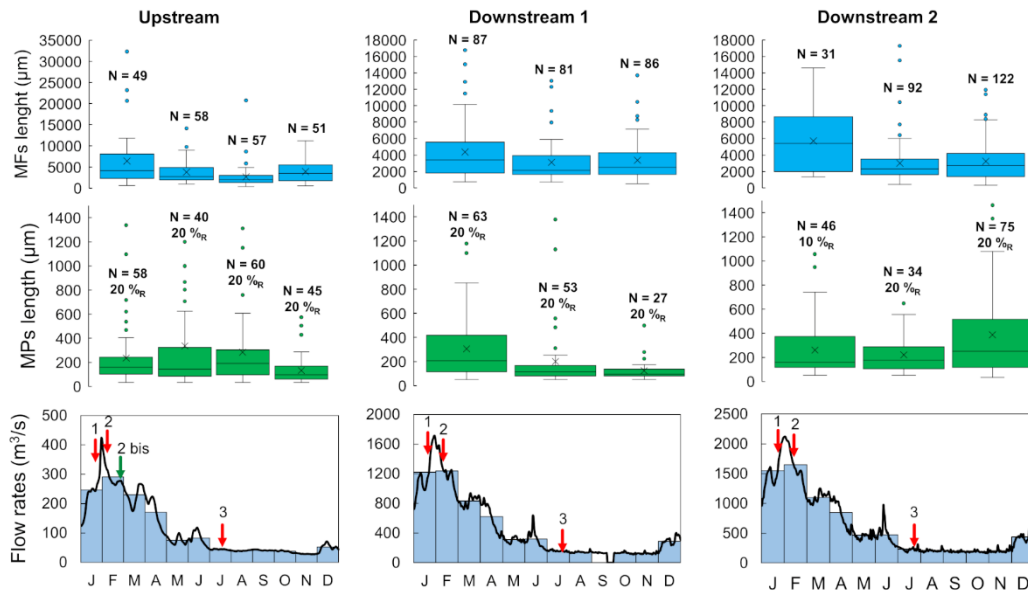
	Median mass concentration during low flow period (µg/L)	Median mass concentration during the flood event (µg/L)
Upstream	10	20
Downstream 1	5	10
Downstream 2	80	50

282

283 3.2. Microfiber and microplastic size distribution

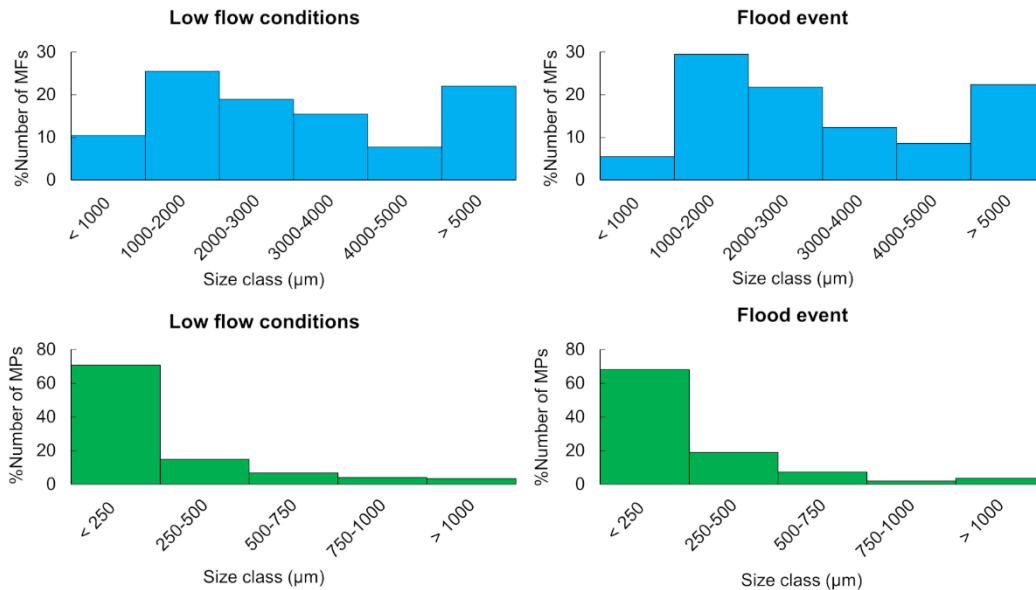
284 Boxplots of the MF and MP sizes relative to river discharge are shown in Figure 4. The size
285 distribution of these particles under low-flow conditions and during the flood event is
286 presented in Figure 5. During the flood event, the median MF sizes of Upstream,
287 Downstream 1, and Downstream 2 samples ranged from 1960 to 5410 µm, whereas the
288 median MP sizes ranged from 115 to 205 µm (Figure 4). The MF size distribution showed
289 the presence of large MFs >5 mm (Figure 5).

290 In low-flow conditions, the median MF sizes of Upstream, Downstream 1, and Downstream 2
291 samples ranged from 2500 to 3480 µm, whereas the median MP size ranged from 96 to 248
292 µm (Figure 4). As for the flood event, the MF size distribution showed the presence of large
293 MFs >5 mm (Figure 5). In contrast, the median MP size was below 250 µm. The MF and MP
294 size distributions during the flood and low-flow conditions are detailed in the supplementary
295 data (Table S2 and Table S3). The mean values were always higher than the median values
296 owing to the presence of large particles (> 5 mm for MFs and > 1 mm for MPs) (Figure 4).



297

298 Figure 4: Boxplots of microfiber and microplastic length relative to the hydrographs of each
 299 sampling site (y-axis may be different depending on the sampling site); mean values are
 300 displayed as crosses; %_R: resuspension percentage; N: number of particles



301

302 Figure 5: Microfiber and microplastic size distributions in low flow conditions and during the
 303 flood event

304 According to Figure 5, the size distributions in low-flow conditions and during the flood event
 305 are similar. MFs sizes were not significantly different between times of low river discharge
 306 and floods, according to the Mann-Whitney test (n=259 in low flow conditions and n=455

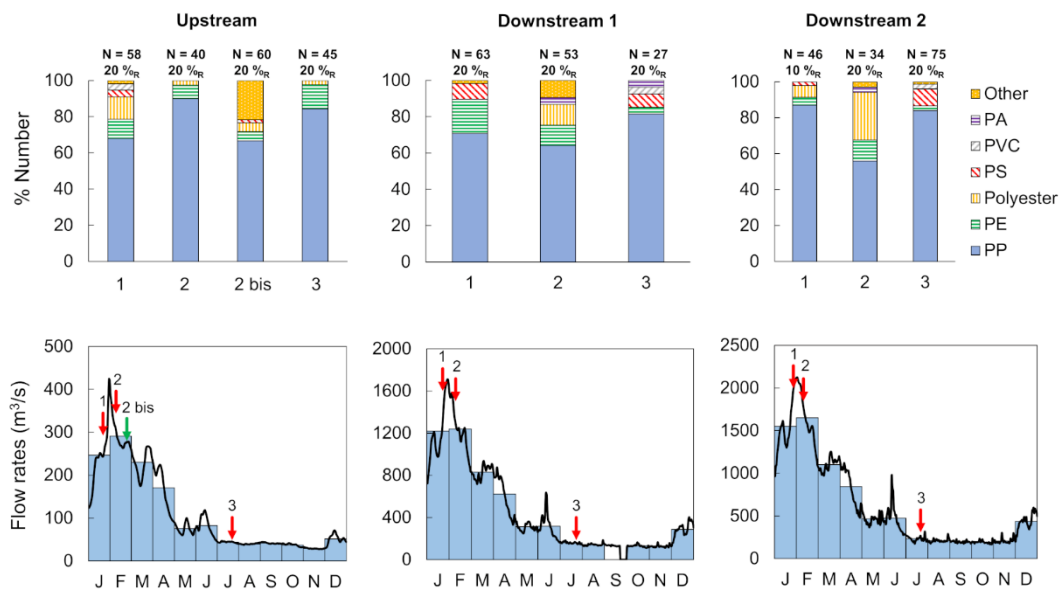
307 during the flood; $p = 0.33$). The same trend was observed for MPs (MW test, $n=147$ in low-
308 flow conditions and $n=354$ during the flood; $p = 0.09$). MFs and MPs found in the analytical
309 blanks were significantly smaller than the particles analysed in the samples (MW test, p
310 <0.05). The median number of MF and MP found in each analytical blank was 9 and 4,
311 respectively, with a median size of 1800 μm and 104 μm , respectively ($n=10$).

312 More than 20% of MFs belonged to the > 5 mm size class (Figure 5). The minimum and
313 maximum MF sizes of all the samples were 313 and 32328 μm , respectively. Even though
314 more than 60% of MFs are smaller than 4 mm, the <1 mm size class is not the most
315 abundant, in contrast with the size distribution of MFs found in atmospheric fallout (Allen et
316 al., 2019). This size distribution differs from that found in a previous study on the Seine
317 River, for which >1 mm was the most significant fraction (Dris et al., 2018).

318 More than 60% of MPs were smaller than 250 μm (Figure 5). This shows the importance of
319 using a small mesh size for MP sampling. A 300 μm net may be inefficient in collecting the
320 most significant MP size classes. The minimum and maximum MP sizes of all samples
321 combined were 32 μm and 2 528 μm , respectively. When all samples were combined (for
322 low flow periods and during the flood), 20% of all MPs were smaller than 80 μm . This may
323 indicate that: (i) the 80 μm net clogged and stored small MPs or (ii) MP aggregates with
324 various MP sizes could have accumulated in the net and could have been separated during
325 organic matter digestion.

326 3.3. Polymer distribution

327 Polypropylene (PP) is the most common polymer (56–90%), followed by polyethylene (PE,
328 3–19%) and polyester (PES, 0–26%) in all samples (Figure 6). The category “other” from
329 Figure 6 contains seven polymers, as detailed in the supplementary data (Table S4). For all
330 samples, PP was always the most abundant polymer. PP and PE are commonly used in
331 packaging, while PES is used in plastic bottles and textiles.



332

333 Figure 6: Percentage of polymers in each sample relative to river discharge at each site. N:
 334 number of microplastics (MP) particles found for a given resuspension volume; %_R:
 335 resuspension percentage. PP: polypropylene; PE: polyethylene; PS: polystyrene; PVC:
 336 polyvinyl chloride; PA: polyamide;

337 The results do not show significant differences in polymer distributions between low flow
 338 conditions and the flood event (Figure 4-6, Table S4). The most significant polymers found in
 339 our samples (PP, PE, PES) are the same as the most representative polymers of
 340 macroplastic debris found in rivers (van Emmerik et al., 2018). These macroplastics may
 341 have formed MPs through fragmentation, which could explain the similarity in the polymer
 342 nature between these studies. The flood event had no significant impact on the type of
 343 polymer transported.

344 3.4. MPs and MFs fluxes in the Seine river

345 These similarities between low flow conditions and floods have strong implications for MF
 346 and MP fluxes in the Seine River. Considering the daily flowrates of each sampling site
 347 (assessed using Pont-sur-Seine, Austerlitz, and Vernon measurements, respectively; see
 348 Figure 2) and the MF and MP concentrations (first and third quartiles, see supplementary
 349 data Table S6), we calculated the MF and MP fluxes as the number of particles flowing per

350 year in the Seine River. We assumed that the MF and MP distributions were the same over
351 the water column. For both MF and MP fluxes, we observed an increasing gradient from
352 Upstream to Downstream 2 (Table 3).

353 The MF flux ranges from 6.6×10^{12} to 9.1×10^{13} items/year, increasing from Upstream to
354 Downstream 2 (Table 3). Dris et al. (2018) previously estimated an anthropogenic MF flux in
355 the Seine River between 2.8×10^{10} and 6.1×10^{11} particles/year. With the hypothesis that
356 65% of the MFs are synthetic, they approximated a flux between 1.8×10^{10} and 4.0×10^{11} of
357 synthetic MFs per year. Owing to a lack of data, Dris et al. (2018) considered only fibers and
358 not the fragments. We estimated much higher fluxes for anthropogenic MF fluxes. This
359 difference may be linked to methodological differences between our studies. Samples from
360 Dris et al. (2018) were collected with an 80 μm net plunged into the Seine River, while we
361 pre-filtered raw water with an 80 μm net. This sampling difference may affect the
362 concentrations observed in samples, as reported by Zheng et al. (2021), who found a
363 difference in concentration of two orders of magnitude between the pre-filtration method and
364 trawl net for the same sampling site.

365 For MPs, we calculated a flux between 4.9×10^{13} and 6.2×10^{14} items/year, increasing from
366 Upstream to Downstream 2. μFTIR analyses coupled with the analysis software siMPle gave
367 an order of magnitude for MP mass fluxes transported at each sampling site (Table 3). MP
368 mass fluxes ranged between 58 and 1675 tonnes/year and increased from Upstream to
369 Downstream 2. The MP mass fluxes at Downstream 2 are extremely high. The highest MP
370 concentrations (Figure 3, Table 2 and Table S6) and highest flowrates were reported at this
371 site, which explains the reported mass fluxes. As reported for the number of particles,
372 Downstream 2 mass fluxes may be significant due to the different WWTP effluents (Figure
373 1). These significant mass fluxes may indicate high MP loads derived from urban water from
374 the Paris megacity. Thus, MP mass fluxes are impacted by urbanisation.

375 Table 3: Estimations of MF and MP fluxes for each sampling point

	MF Fluxes in items/year	MPs Fluxes in items/year	MPs Fluxes in tonnes/year
Upstream	6.6-7.1x10 ¹²	4.9-6.0x10 ¹³	58-74
Downstream 1	4.4-4.8x10 ¹³	1.8-2.2x10 ¹⁴	56-146
Downstream 2	4.9-9.1x10 ¹³	3.6-6.0x10 ¹⁴	924-1675

376

377 The January-February 2018 flood event corresponded to 14.5% of the year (in time) but
 378 contributed 40% of the microplastic and microfiber annual loads, indicating the important role
 379 of flood events as microplastic inputs in the Seine River. This is consistent with the data
 380 collected by Wagner et al. (2019), who found that 90% of the plastic load in freshwater could
 381 be transported in 20% of the year. According to our results, we observed a significant
 382 increase in MP mass fluxes from upstream to downstream sites, mainly caused by the
 383 increase in flow rates and not by a significant concentration increase. For this reason, high
 384 water levels may significantly increase the plastic load in freshwater. For macroplastic fluxes,
 385 van Emmerik et al. (2019) observed an increase of one order of magnitude during high water
 386 levels in the Seine River. According to Tramoy et al. (2020a), flood events may effectively
 387 flush plastic debris from upstream to downstream regions owing to their high flow rates.

388 Tramoy et al. (2021, under review) estimated that the macroplastic mass fluxes from the
 389 Seine River estuary to the ocean range between 100 and 200 metric tons per year. The high
 390 value found in Downstream 2 is most likely linked to the significant mass concentrations and
 391 high flowrates for this sampling point. Although MP mass concentrations are rarely assessed
 392 in freshwater systems, our results are consistent with the estimations from Rodrigues et al.
 393 (2018), but are one or two orders of magnitude higher than other estimations (Haberstroh et
 394 al., 2021; Kataoka et al., 2019). These estimations may indicate significant plastic inputs
 395 from the Greater Paris region. However, our estimation does not correspond to MP mass

396 discharge from land to sea, but only reflects the MP mass flux at certain sampling points.
397 More data should be collected on plastic mass fluxes, particularly in urban rivers, to confirm
398 the significant microplastic loads we observed.

399 4. Conclusion

400 We evaluated the MF and MP concentrations at three different upstream to downstream
401 sampling sites during both low-flow conditions and a flood event. The results of this study
402 show that the concentrations are of the same order of magnitude regardless of the
403 hydrological conditions. The urbanisation gradient did not significantly influence these
404 concentrations. Similarly, the flood and urbanisation gradient did not significantly affect the
405 size and polymer distributions at the different sampling sites. PP, PE, and PES correspond
406 to more than 60% of all polymers found. However, MP mass fluxes are strongly impacted by
407 the urbanisation gradient, as we observed very high mass fluxes at the most downstream
408 sampling site (924-1675 tonnes/year at Downstream 2). The January-February 2018 flood
409 event, which corresponds to 14.5% of the year (in terms of time), contributed 40% of the MF
410 and MP loads in the Seine River. In the future, greater attention should be paid to flood
411 events, as they constitute major pathways for microlitter contamination. A better
412 understanding of MF and MP dynamics in freshwater environments is needed to evaluate
413 the impact of transitory events such as floods and significant rainfall events.

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557

558 Supplementary data

559 Table S1: Daily flowrates, water levels and sampling volumes corresponding to each sample

560 (data from <http://hydro.eaufrance.fr>)

		Upstream	Downstream 1	Downstream 2	
1	01/26/2018	Flowrates (m ³ /s)	280	1570	1880
		Water level (m)	6.19	5.49	3.39
		Sampling volume (L)	23	27	19
2	02/05/2018	Flowrates (m ³ /s)	330	1460	1940
		Water level (m)	6.28	5.28	5.03
		Sampling volume (L)	24	24	23
2bis	02/21/2018	Flowrates (m ³ /s)	256	-	-
		Water level (m)	6.19	-	-
		Sampling volume (L)	24	-	-
3	07/17/2018	Flowrates (m ³ /s)	45	155	241
		Water level (m)	4.01	0.97	3.36
		Sampling volume (L)	21	20	20

561

562 Table S2: Summary of microfibers and microplastics sizes collected during a flood event

Microfibers	N	Mean (µm)	Standard deviation (µm)	Median (µm)	Interquartile range (µm)
Upstream	164	4153	4388	2716	3092
Downstream 1	168	3762	3036	2670	2983
Downstream 2	123	3699	3254	2453	2863

563

Microplastics	N	Mean (µm)	Standard deviation (µm)	Median (µm)	Interquartile range (µm)
Upstream	158	278	351	171	185
Downstream 1	116	258	255	150	215
Downstream 2	80	243	201	163	198

564

565 Table S3: Summary of microfibers and microplastics sizes collected during low flow

566 conditions

Microfibers	N	Mean (µm)	Standard deviation (µm)	Median (µm)	Interquartile range (µm)
Upstream	51	3923	2705	3482	3536
Downstream 1	86	3363	2531	2512	2608
Downstream 2	122	3221	2337	2687	2675

567

Microplastics	N	Mean (µm)	Standard deviation (µm)	Median (µm)	Interquartile range (µm)
Upstream	45	133	116	96	90
Downstream 1	27	124	91	96	56
Downstream 2	75	386	409	249	390

568

569 Table S4: Details of the category "Other" from Figure 6

Polymers from the category "Other"	Abbreviation
Acrylonitrile butadiene styrene	ABS
Cellulose Acetate	CA
Polyacrylonitrile	PAN
Polyamide	PA
Polyurethane	PU
Polyvinyl Acetate	PVAC
Styrene butadiene rubber	SBR

570

571 Table S5 : Details of the polymers found in the different samples

	Number of polymer types found	Details
260118_Upstream	7	CA, PAN, PE, PES, PP, PS, PVC
260118_Downstream 1	5	ABS, PE, PP, PS, SBR
260118_Downstream 2	4	PE, PES, PP, PS
050218_Upstream	3	PE, PES, PP
050218_Downstream 1	5	PA, PE, PES, PP, PVAC
050218_Downstream 2	5	PA, PE, PES, PP, PU
210218_Upstream	6	PAN, PE, PES, PP, PS, PVAC
170718_Upstream	3	PE, PES, PP
170718_Downstream 1	5	PA, PE, PP, PS, PVC
170718_Downstream 2	5	ABS, PE, PP, PS, PVC

572

573

574 Table S6: MF and MP concentrations (first and third quartile) for each sampling site

	First and third quartile (concentration in microfibers per liter)	First and third quartile (concentration in microplastics per liter)	First and third quartile (concentration in μg of microplastics per liter)
Upstream	1.9-2.0	14.3-17.4	16.8-21.3
Downstream 1	3.0-3.4	12.3-15.6	3.9-10.3
Downstream 2	2.5-4.6	18.5-30.4	47.0-85.1

575