



**HAL**  
open science

## Amount, composition and sources of macrolitter from a highly frequented roadway

L. Ledieu, R. Tramoy, S. Ricordel, D. Astrie, B. Tassin, Johnny Gasperi

### ► To cite this version:

L. Ledieu, R. Tramoy, S. Ricordel, D. Astrie, B. Tassin, et al.. Amount, composition and sources of macrolitter from a highly frequented roadway. *Environmental Pollution*, 2022, pp.119145. 10.1016/j.envpol.2022.119145 . hal-03614075

**HAL Id: hal-03614075**

**<https://enpc.hal.science/hal-03614075>**

Submitted on 22 Jul 2024

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution - NonCommercial 4.0 International License



31 rates show a linear correlation with the road traffic. Such data are of prime interest since they enable to  
32 determine the potential contribution of road traffic to plastic fluxes to the environment.

33

## 34 **Keywords**

35 Macrolitter, road runoff, macroplastics, road traffic, deliberate littering, accidental littering

36

## 37 **1. Introduction**

38 Macrolitter constitutes an environmental, societal and economic issue, because it affects the  
39 environmental quality, the human health and the economic development (Thevenon et al., 2014). The  
40 term “litter” generally includes all misplaced solid wastes (Forbes, 2009), which can be seen as the  
41 most visible indicator of environmental contamination (Queensland Department of Environment and  
42 Heritage Protection, 2016). Plastic debris specifically represent a big challenge since more than 1 t of  
43 plastic was produced per person currently living on earth between 1950 and 2017 (Heinrich Böll  
44 Stiftung et al., 2020) and countries have difficulties managing the resultant volume of plastic debris  
45 (Borrelle et al., 2020), which leads to potential leakages to the environment. Recent research efforts  
46 have been made to quantify these outcomes (Edelson et al., 2021). For instance, Borrelle et al. (2020)  
47 estimated that 11% of the plastic waste generated in 2016 entered the waterways. Nevertheless, given  
48 the uncertainties of such estimations, accurate rates of debris leaked to the environment are difficult to  
49 establish (Edelson et al., 2021; Lechthaler et al., 2020).

50 Some researches estimate that most debris entering the ocean come from urban areas (Poeta et  
51 al., 2016) and mainly transported by rivers (Lechthaler et al., 2020; Schmidt et al., 2017). Once in the  
52 open ocean, debris are difficult to remove and their sources are often untraceable (Jambeck et al.,  
53 2015), the understanding of riverine macrolitter and plastic debris sources requires more research (Al-  
54 Zawaidah et al., 2021). Debris can be transferred to waterways by direct dumping or by natural  
55 transport processes (van Emmerik and Schwarz, 2020). Even if the negative impact of litter has been  
56 pointed out for more than 40 years, some questions remain open (Bolingbroke et al., 2018). Notably,

57 data linking transport activity to fluxes to receiving environments are scarce (Schmidt et al., 2017).  
58 Methodologies to identify macrolitter input sources should therefore be developed (Schirinzi et al.,  
59 2020) and detailed knowledge on litter composition, where debris are produced and introduced to  
60 waterways are needed (Windsor et al., 2019). This would also help to better identify the factors  
61 driving the high variabilities observed in macrolitter studies (Treilles et al., 2021) and to assess  
62 mitigation strategies (Al-Zawaidah et al., 2021).

63 Significant contributions from urban runoff to riverine macrolitter, including plastic debris,  
64 was already demonstrated (Weideman et al., 2020). Because field data are still insufficient (Treilles et  
65 al., 2021; Windsor et al., 2019), a continuous monitoring of litter in urban and suburban areas was thus  
66 recommended (Schirinzi et al., 2020; Tramoy et al., 2022a). Moreover, road runoff constitutes a  
67 potential non-point source of pollution (Robertson et al., 2019) as roadside ditches may connect land-  
68 based sources to waterways (Pietz et al., 2021). The impacts of roadway litter and the huge costs spent  
69 for its collection are a concern since the 1950's (Forbes, 2009), mainly in the USA. Associative  
70 projects were created to perform cleaning operations and engineering companies were solicited to  
71 conduct litter reports, but few scientific researches reported the composition and rates of roadway  
72 macrolitter accumulation. To the best of our knowledge, this kind of data does not exist in Europe yet.

73 In this context, a monitoring of macrolitter was launched in August 2020 on the roadsides of a  
74 highly frequented roadway. This study therefore aims at (i) providing new insights on the amount, the  
75 composition and the fluxes of roadway macrolitter including plastic debris, (ii) assessing their input  
76 sources to define littering behavior and (iii) identifying the main driving/influencing factors in the rate  
77 of debris accumulation to estimate mean annual loads, through a one-year survey on a highly  
78 frequented French roadway.

79

## 80 **2. Materials and methods**

### 81 **2.1. Sampling site and sampling procedure**

82            Sampling site is described in detail in the co-submitted data article (Tramoy et al., 2022b). It  
83 consists on a retention pond collecting stormwater from an 800 m portion of a highly frequented  
84 roadway (~ 90,000 vehicles/day), south part of the Cheviré Bridge in Nantes, France (Fig. 1).

85            Sampling of all visible macrolitter was performed by hand into the retention pond over one  
86 year following the procedure described in the co-submitted data paper (Tramoy et al., 2022b).  
87 Macrolitter were then characterized according to the OSPAR (Convention for the Protection of the  
88 Marine Environment of the North-East Atlantic) / TGML (Technical Group on Marine Litter under the  
89 Marine Strategy Framework Directive) classification (MSFD Technical Group on Marine Litter, 2013)  
90 and weighted by category of specific items. Ten samples, labelled from C1 to C10, were collected  
91 between August 2020 and July 2021. Each sample corresponds to an accumulation period of  
92 macrolitter in the retention pond with an associated precipitation amount in mm (Fig. 2).

93

## 94            2.2. Input source assessment

95            Macrolitter input sources (i.e. motorists, improperly secured loads, overflowing containers,  
96 vehicle accidents) can be identified based on material category (Burns & McDonnell, 2020) and/or  
97 item's economic sectors (Crosti et al., 2018). The MSFD G codes were thus categorized in six groups,  
98 (i) food-related products, (ii) hygiene/cosmetics/medical products, (iii) tobacco products, (iv)  
99 building/industrial materials, (v) car parts and (vi) clothing/rags, according to their uses/sectors. Food-  
100 related products therefore include multipack rings (G1), shopping bags (G3), bottles and their labels  
101 (G7, 8, 124 and 200), food containers (G10, 150, 153 and 176), caps/lids and their rings (G21, 24 and  
102 178), food wrappers (G30 and 177), lollypop and ice-cream sticks (G31 and 165), tableware (G33.2,  
103 34.2 and 181), straws and stirrers (G35), mesh vegetable bags (G37) and cans (G175). Sanitary items  
104 include cosmetic and pharmaceutical containers (G11 and 12), gloves (G40 and 41), cotton buds (G95),  
105 sanitary towels (G96), earplugs (G124), condoms (G133), tissues and paper towels (G158), and  
106 medical items (G100 and 211). Tobacco products include cigarette packaging (G25 and 152), lighters  
107 (G26), butts and filters (G27). Building/industrial materials and packaging include strapping bands

108 (G66), industrial packaging and sheets (G67), fiber glass (G68), foams (G74), masking tape (G87),  
109 plastic construction waste (G89), cable ties (G93), tape and maintenance devices (G124), cardboards  
110 packaging (G148), industrial scraps (G186), wires and fences (G191). Car parts only include the  
111 parent code G19 and clothing/rags the G137. This grouping also answers the European directive on  
112 single-use plastics by considering 9 of the 10 items addressed by this directive (cotton buds, cutlery,  
113 plates, straws and stirrers, food containers, cups for beverage, beverage containers, cigarette butts,  
114 plastic bags, packets and wrappers, wet wipes and sanitary items; Directive (EU) 2019/904).

115

### 116 2.3. Calculation of total anthropogenic litter fluxes and plastic litter loads

117 Annual loads (in kg/y) of total anthropogenic and plastic debris generated in such a context  
118 were extrapolated using the relationship between the mass of macrolitter and the accumulation period,  
119 when these variables were significantly correlated. The correlations were evaluated with the Spearman  
120 correlation coefficients R (Spearman, 1904) and the associated p-values. These analyses were done  
121 with the Microsoft Excel add-on XLSTAT 2019 (Addinsoft, 2019). By referring to the surface of the  
122 roadway drained by the stormwater, annual loads were also assessed (in kg/y/ha).

123

## 124 3. Results and discussion

### 125 3.1. Macrolitter composition

126 During this one-year survey, a total of 36,439 items were collected, representing 88.5 kg of  
127 macrolitter (Fig. 3). The debris belong to 104 types of items from all categories of materials. Full data  
128 and detailed descriptions are provided in a data repository (Tramoy et al., 2021) and in the co-  
129 submitted data paper (Tramoy et al., 2022b). Fig. 3 illustrates the percentages of all categories of  
130 materials by count (a) and by dry weight (b) for each campaign and in total.

131 The most specific items featuring in the Top 10 items by count are plastic pieces (between 2.5  
132 and 50 cm, 31%), cigarette butts and filters (18%), polystyrene pieces (between 2.5 and 50 cm, 16 %)

133 and foam packaging and insulation (11%; Tramoy et al., 2022b). These results are consistent with the  
134 general predominance of plastic fragments reported in a French urban river (Tramoy et al., 2022a) and  
135 with the high proportions of cigarette butts and polystyrene pieces noticed in urban stormwater from  
136 Cape Town (Weideman et al., 2020). A majority of plastic pieces and cigarette butts was also  
137 observed on American roadways (Keep America Beautiful, 2021). This composition also shows  
138 similarities with those of European rivers (González-Fernández et al., 2021) and macrolitter on  
139 riverbanks (Schöneich-Argent et al., 2020). The most specific items featuring in the Top 10 by mass  
140 are plastic pieces (between 2.5 and 50 cm, 24%), cardboard (boxes and pieces, 13%), foam packaging  
141 and insulation (6%), and wood pieces (6%; Tramoy et al., 2022b). Items constituted of plastic, rubber,  
142 paper/cardboard, manufactured wood and metal were always found in the samples (Fig. 3). However,  
143 the macrodebris collected present a low diversity of components with Top 10s constituting 92% and  
144 72% of all collected items by count and by mass, respectively.

145 Plastic categories were predominant in each campaign, varying from 65% (C4) to 98% (C1)  
146 by count of items (Fig. 3a), and from 52% (C9) to 80% (C1) in mass (Fig. 3b). These plastic levels are  
147 similar to those observed in urban stormwater from a small French catchment (Sucy-en-Brie, Treilles  
148 et al., 2021), in a small French urban river (Huveaune, Tramoy et al., 2022a) as well as in large  
149 European rivers (Tiber, Crosti et al., 2018; Ems, Weser and Elbe, Schöneich-Argent et al., 2020;  
150 Rhine and Meuse, van Emmerik et al., 2020). It confirms both the predominance of plastics in  
151 macrolitter from urban areas and the significant contribution of road runoff to the presence of plastics  
152 in urban stormwater and subsequently in rivers.

153 To our best knowledge, the only other studies on plastic debris carried on American and  
154 Canadian roadways showed lower percentages of plastic items (31%, AET Group Inc., 2020; 39%,  
155 Keep America Beautiful, 2021). However, the methods and classifications used for these surveys  
156 differ, which does not enable a direct comparison of the results. For instance, tobacco-related products  
157 and composite materials are often pooled in a specific category, different from that of plastics (Burns  
158 & McDonnell, 2020; Environmental Resources Planning, 2020). Moreover, the size categories  
159 considered in such studies differ from those considered in the OSPAR / TGML classification. For

160 example, the litter studies carried out in Texas and Pennsylvania distinguished the items bigger and  
161 smaller than four inches (about 10 cm; Burns & McDonnell, 2020; Environmental Resources  
162 Planning, 2020) whereas this study considered all items above 1 cm. Comparisons are therefore  
163 difficult (Castro-Jiménez et al., 2019), supporting the critical need for a standardization of  
164 methodologies (Bolingbroke et al., 2018) and for more data collection on European roadways.

165 Other discrepancies can derive from the different size categories considered in those studies.  
166 van Emmerik et al. (2018) and Vriend et al. (2020) considered the macroplastics above 5 cm in the  
167 Saigon River (Vietnam) and the Rhine River (Netherlands), respectively, whereas (Schöneich-Argent et  
168 al., 2020) considered the items above 0.5 cm in three German rivers (Ems, Weser and Elbe). In order  
169 to estimate mass flows of plastic items, these authors reported mass ratios from the collected particles.  
170 Van Emmerik et al. (2018), Vriend et al. (2020) and (Schöneich-Argent et al., 2021) estimate an  
171 average mass per plastic pieces of 5.9 g (Saigon River, n = 614), 5.4 g (Rhine River, n = 311) and 5.3  
172 g (Ems, Weser and Elbe, n = 1,991), respectively. In our study, the mass distribution shows that 94%  
173 of collected plastic items had a mass lower than 1.9 g with a median value of 1.2 g and a mean value  
174 of 1.7 g (n = 30,777; Tramoy et al., 2022b). The narrow distribution of mass values probably results  
175 from the specific context of the sampling site. The traffic can cause the crushing of large items,  
176 suggesting that road runoff would be primarily a source of small, lightweight plastic items. Moreover,  
177 this sampling site offers a better opportunity to collect small items than in rivers.

178 The predominant plastic items reported in ocean ecosystems and beaches mostly include  
179 single-use packaging after cigarette butts (Watt et al., 2021) and these items are also frequently  
180 collected in riverine litters (González-Fernández et al., 2021; van Emmerik et al., 2020), this is why a  
181 European directive (Directive (EU) 2019/904) was drawn to tackle their use. Cigarette butts, plastic  
182 bags, bottles, caps and lids, food packaging, plastic labels, cable ties and medical containers were  
183 actually found during the ten campaigns (Tramoy et al., 2021). These results are not surprising since  
184 packaging industry is the main user of plastic (PlasticsEurope, 2019) and since this kind of plastic  
185 waste has a very short useful life (Heinrich Böll Stiftung et al., 2020). Considering this, limiting the  
186 use of single-use plastics for bags, food and beverage containers, tableware and cigarette butts through



187 a directive at a European scale constitute a first promising mitigation strategy. Nevertheless, the  
188 COVID-19 pandemic also increased the consumption of single-use plastics such as facemasks  
189 (Battisti, 2021; United Nations Environment Programme, 2021). Although the studied period was  
190 during this health crisis, and that facemasks were actually found in almost every campaign (Tramoy et  
191 al., 2021), they only represent a very small fraction of the debris collected (0.2% in number), and have  
192 not been explicitly considered. The increase of such personal protective equipment was already  
193 noticed in American roadside ditches (Pietz et al., 2021). Compared to the useful life of this kind of  
194 plastic waste, the environmental lifetime of single-use items is supposed to be long but this assumption  
195 is not based on peer-reviewed literature (Ward and Reddy, 2020). Policymakers therefore required  
196 additional data and typological analysis to efficiently reduce the single-use plastics pollution (United  
197 Nations Environment Programme, 2021).

198

### 199 3.2. Deliberate vs accidental littering

200 Roadside debris can be deliberately littered or accidentally lost by motorists and pedestrians  
201 (Forbes, 2009). In this study, only motorists may use the bridge, debris therefore derive from  
202 uncovered trucks, unsecured loads, human negligence, loss of vehicle parts by wear or by vehicle  
203 accidents and incivilities. These input sources can be identified according to the type of collected  
204 items (Burns & McDonnell, 2020) and their uses or economic sectors (Crosti et al., 2018). In this way,  
205 items have been categorized in six groups to discriminate deliberate from accidental littering. In this  
206 study, food-related, hygiene/cosmetic/medical and tobacco products were considered as deliberately  
207 littered and building/industrial materials, car parts and clothing/rags as accidentally lost (Fig. 5). The  
208 type of items included in each group is given in section 2.2. This grouping was possible for only 43%  
209 of the collected items (by count and by dry weight) as many debris were fragments whose uses or  
210 sectors couldn't be identified. The variability and the mean percentages of each group during the ten  
211 campaigns are represented by count (a) and by mass (b) in Fig. 4.

212 Building/industrial materials exhibited the highest mean percentages both by count of items  
213 (Fig. 4a) and by dry weight (Fig. 4b), demonstrating that accidental leaks can be more important than  
214 deliberate ones. In contrast, hygiene/cosmetics/medical products, car parts and clothing/rags showed  
215 the lowest mean percentages both by count of items (Fig. 4a) and by dry weight (Fig. 4b), highlighting  
216 a low contribution of those sources. Tobacco products exhibited the second highest mean percentage  
217 by count of items (Fig. 4a) but as they are constituted by small and lightweight items, they only  
218 represented a low contribution in the masses of macrolitter collected (Fig. 4b). In this way, food-  
219 related products exhibited a significant contribution by count of items (Fig. 4a) and their mean  
220 percentage is the second highest by mass (Fig. 4b). In this study, accidental leaks thus appear to be  
221 predominant, constituting a median percentage of 62.8% in the masses of macrolitter (Table 1).  
222 Nevertheless, losses of car parts by wear or accidents as well as clothing/rags losses by human  
223 negligence only represented low contributions (Fig. 4). The main leaks therefore result from unsecured  
224 truck or trailer loads during the transport of goods for building and industrial activities. Contrarily to  
225 some assumptions and even if 28% of the French motorists admit to litter on highways (Vinci  
226 Autoroutes, 2021), deliberate leaks do not appear to be the main source of debris on the Chevre  
227 bridge.

228 The litter research study carried in Pennsylvania found higher contributions from deliberate  
229 littering but the collected items were also dumped by pedestrians, which represented 25% of the inputs  
230 (Burns & McDonnell, 2020). In contrast, litter researches in Tennessee also showed a predominance  
231 of accidental leaks (Nowakhtar, 2016). In each case, these trends were highly variable over space  
232 according to roadway types (Burns & McDonnell, 2020; Nowakhtar, 2016). On a bridge, deliberate  
233 littering may be decreased by the visible proximity of the waterway compared to classic highways and  
234 the stronger impact of the wind may enhance the accidental loss of items. These differences should  
235 also be interpreted with caution, especially since these groupings were only made for 43% of the items  
236 collected during this survey and as accidental leaks are more difficult to detect (Schultz et al., 2013).  
237 For example, the litter study in Tennessee considered miscellaneous papers as accidentally lost

238 (Nowakhtar, 2016), which was not the case in our study. Identifying the likely sources of roadway  
239 macrolitter thus needs more harmonized approaches.

240 Despite a low diversity of components in the collected debris during the ten campaigns  
241 (section 3.1.), the percentages of the six type of items presented a significant variability (Fig. 4). This  
242 means that the contribution of deliberate and accidental littering may vary over time (Table 1). The  
243 mass percentages of items considered as accidentally lost ranged from 42.0% to 90.8% (Table 1). The  
244 maximum was observed during the sixth campaign (C6, Table 1), suggesting the involvement of the  
245 Bella storm occurring during its period (on December 27 and 28, 2020; Tramoy et al., 2022b) in the  
246 input of debris. Indeed, huge amounts of industrial sheets, packaging and foams were collected  
247 (Tramoy et al., 2021) and the loss of these lightweight items from uncovered trucks could have been  
248 accentuated by the gusting winds reaching 90 km/h during the storm. In contrast, C2, C7 and C8  
249 showed a slightly higher contribution of deliberate littering to the collected masses (Table 1).  
250 Nevertheless, these variations exhibited no significant correlation neither with climatic variables (i.e.  
251 maximum speeds of wind, maximum temperatures, rain amounts and seasons of sampling), nor with  
252 the traffic conditions (i.e. percentages of heavy vehicles and daily heavy vehicle traffic). Indeed, these  
253 variations result from different reasons: lower amounts of industrial sheets, packaging and foams for  
254 C2; larger amounts of plastic rings, gloves and glass bottles for C7; and larger amounts of food  
255 containers and wrappers for C8 (Tramoy et al., 2021). To better identify the factors driving the  
256 littering behavior and to understand the observed variabilities, further studies should be conducted on  
257 lower temporal resolutions. Moreover, a better characterization of this variability could be carried out  
258 with the calculation of diversity indices as is beginning to be done for beach litter (Treilles et al.,  
259 2021).

260 Plastic items exhibited similar contributions. Deliberate and accidental leaks median  
261 percentages represented 42.0% and 58.0%, respectively. These results highlight the potential reduction  
262 of plastic debris by better securing truck or trailer loads. Littering prevention strategies should  
263 therefore pay more attention to accidental leaks.

264

### 265 3.3. Relationship with the accumulation period and the traffic

266 The number of collected items and the corresponding masses were variable during the ten  
267 campaigns. Fig. 5 illustrates this variability for all collected debris and also for plastic debris specially,  
268 according to rain amounts and cumulative traffic.

269 Rates of macrolitter accumulation may depend on climatic variables like precipitation  
270 (Robertson et al., 2019; Treilles et al., 2021) and wind (Lechthaler et al., 2020), as well as from the  
271 road traffic (Chapman and Bomford, 2020; Pietz et al., 2021). However, in our study, except for the  
272 sixth campaign (C6, section 3.2.), the total masses of litter exhibited no correlation neither with the  
273 maximum speed of gusting winds during each period nor with the total rain amount of each campaign  
274 (Fig. 5a; Tramoy et al., 2022b). Indeed, with similar rain amounts the fourth (C4) and the fifth  
275 campaigns (C5) exhibited different masses of litter, and similar masses of litter were collected during  
276 the eighth (C8) and the ninth (C9) campaigns while rain amounts were significantly different (Fig. 5a).  
277 The absence of such a relationship was already observed (Castro-Jiménez et al., 2019; Weideman et  
278 al., 2020) and must result in our case from: (i) the high number of factors involved in littering  
279 (Robertson et al., 2019), (ii) the long period of waste accumulation integrating various climatic  
280 conditions and (iii) the sampling site that allows the transport of items from the lateral gutters to the  
281 retention pond even with low rain amounts.

282 Among the ten campaigns, the fourth (C4) exhibited the lowest mass of macrolitter, the tenth  
283 (C10) the heaviest (Fig. 3b) and these variations followed the traffic fluctuations (Fig. 5a and b). A  
284 significant positive correlation was observed between the cumulative traffic at the Cheviré bridge and  
285 the mass of macrolitter collected during each campaign (Fig. 5b). Without considering the exceptional  
286 mass collected during the sixth campaign (C6), this correlation was even more significant with a  
287 Spearman coefficient of 1 ( $p$ -value  $< 0.0001$ , Fig. 5b). The road traffic is therefore the main driving  
288 factor determining the masses of macrolitter collected. Moreover, as this parameter is relatively  
289 constant at the Cheviré bridge, the masses of macrolitter also showed a significant positive correlation  
290 with the duration of each campaign (Fig. 5c), highlighting a constant litter accumulation in the pond  
291 over time. The increase of macrolitter, including plastic debris, with higher road traffic was already

292 demonstrated (Chapman and Bomford, 2020; Pietz et al., 2021). In the case of the Cheviré bridge, this  
293 relationship was a significant linear correlation both with the masses of macrolitter (Fig. 5b and c) and  
294 with the masses of plastic debris ( $R = 0.97$ ,  $p\text{-value} < 0.0001$ ). The same correlations were observed  
295 with heavy vehicle traffic as their rates were constant (Tramoy et al., 2022b).

296 The linear correlation between the masses weighted and the accumulation periods allowed the  
297 extrapolations of annual loads and densities of macrolitter and plastic items. At the Cheviré bridge,  
298 around 88 kg/yr of macrolitter are generated, among which 50 kg are plastics (Table 2). It represents a  
299 density of 24 kg/yr/ha (Table 2). Considering the mean annual loads measured by Treilles et al. (2021)  
300 in urban stormwater (i.e. 0.4 kg/y/ha to 1.7 kg/y/ha), annual loads of plastic items at the Cheviré  
301 bridge are very high. Highly frequented highways therefore represent a significant source of plastic  
302 debris in large cities.

303 According to Burns & McDonnell (2020), roadway types play a key role in the rate of  
304 macrolitter accumulation. It is therefore difficult to assess the representativeness of the results  
305 obtained for the studied highway. According to the mean daily traffic on French roads (based on the  
306 annual traffic from 2018), 5% of the highway sections (i.e. 1046 kms) present similar traffic  
307 conditions to the Cheviré bridge at a national scale (<https://www.data.gouv.fr>). Moreover, even if  
308 roadway types induced variable rates of macrolitter accumulation, the Pennsylvania Litter Research  
309 Study demonstrated that litter composition varied a little (Burns & McDonnell, 2020). It therefore  
310 suggests that inputs similar to those of the Cheviré bridge could be expected on 5% of the French  
311 highway sections, which would represent 115 t/yr. Nevertheless, the inputs of macrolitter at a national  
312 scale are expected to be much higher as the road traffic was not measured on 22% of the highway  
313 sections and as 6% have a higher road traffic than the Cheviré bridge (<https://www.data.gouv.fr>).  
314 Indeed, around 25 t of macrolitter are collected by the highway workers of the Vinci network (4 443  
315 km) each day, among which plastics are the dominant items (Vinci Autoroutes, 2021). This amount is  
316 however difficult to interpret as the sampling locations were not specified and could comprise the  
317 highway service areas.

318           Moreover, the extrapolations based on the correlation equation are slightly lower than those  
319 based on the total masses of macrolitter and plastic items collected during this survey (Table 2). This  
320 difference results from the exceptional mass weighted during C6 (Fig. 5) because of the Bella storm,  
321 underscoring the important role of this kind of extreme climatic event in macrolitter inputs. The  
322 extreme and punctual nature of these events makes them difficult to sample and to quantify but these  
323 results show the importance to consider them. Not considering these exceptional events may lead to an  
324 underestimation of the fluxes of macrolitter and plastic debris. Considering that with climate change  
325 the frequency and intensity of these extreme climatic events will increase (Antoni et al., 2020), efforts  
326 should be done to perform a better quantification and consideration of these events.

327           Cleaning operations on land are an efficient way to decrease macrolitter loads (Tramoy et al.,  
328 2019) and as demonstrated by this study, retention ponds or other structures collecting macrolitter also  
329 constitute significant buffers limiting efficiently their spreading. However, the accumulation of  
330 macrolitter in such structures raises questions about their chemical and ecological impact in the long  
331 term. Moreover, retention ponds were not designated for this aim and many road sections do not have  
332 any inducing that stormwater including their plastic loads can thus be directly dumped into waterways  
333 (Watt et al., 2021). In addition to decreasing the use of single-use plastics, better securing truck and  
334 trailer loads, find alternatives to the use of plastic in the automotive industry and awareness strategies  
335 could therefore constitute effective prevention measures.

336

#### 337           **4. Conclusions**

338           To the best of our knowledge, no data exists on roadway macrolitter in Europe and this one-  
339 year survey was led to address this need. This study actually enabled the identification of roadway  
340 macrolitter typologies, driving factors and likely sources at the Cheviré bridge in Nantes Metropole  
341 (France). Our results show a low diversity of components and the large predominance of plastic  
342 debris. Among the plastic items, single-use packages were recurring, supporting the already initiated  
343 reduction of their production. With an annual density around 24 kg/y/ha at the Cheviré bridge, it  
344 appears that roadway macrolitter represents significant contributions to the fluxes of plastic items in

345 stormwater from urban areas. The main contribution to roadway macrolitter seems to have an  
346 accidental nature. This statement suggests that prevention efforts need to be based mainly on a more  
347 efficient protection of truck or trailer loads during building and/or industrial activities. Moreover, the  
348 loads of macrolitter and plastic items are fully dependent on traffic levels. In the case of constant  
349 traffic conditions, inputs of debris therefore present constant accumulation rates in the pond over time.  
350 Nevertheless, the accumulation rates of debris can obviously be enhanced by extreme climatic events.

351         This kind of survey is needed to evaluate the accumulation rates and specific sources of  
352 macrolitter in urban areas and thus needs to be related to the road traffic. Up until now, most surveys  
353 on roadway macrolitter were performed by engineers in the USA and Canada. The results are not  
354 readily accessible and methods vary from the macrolitter classifications used in European surveys.  
355 Scientific data on European roadways are therefore required. It again points out that the methods used  
356 in such surveys have to be standardized. Moreover, our study provides a new vision of predominant  
357 input sources of roadway macrolitter. Strategies to reduce macrodebris must therefore be adapted with  
358 regard to these data. More researches at different scales in time and space are however needed to help  
359 identify and understand the variability in littering behavior. The calculation of diversity metrics could  
360 also provide useful information on the variability of their sources. Finally, cleaning operations and  
361 retention ponds collecting the stormwater from highway runoff are a first efficient way to limit the  
362 spreading of debris to waterways but stronger prevention strategies have to be prioritized for  
363 constraining their ecological impact.

364

## 365 **Acknowledgments**

366 We would like to thank the DIR Ouest for their collaboration and for providing the data on traffic  
367 levels. This work, as part of the Plasti-nium Research project, was funded by the Région des Pays de  
368 la Loire (France) and by Nantes Métropole. The University Gustave Eiffel also supported this work by  
369 funding the apprenticeship of D. Astrié. Authors are also grateful to the editor and reviewers for their  
370 comments and suggestions to improve the first draft of the manuscript.

372 **References**

- 373 Addinsoft, 2019. XLSTAT statistical and data analysis solution. Long Island. NY. <https://www.xlstat.com>.
- 374 AET Group Inc., 2020. 2020 Litter Audit for the City of Toronto.
- 375 Al-Zawaidah, H., Ravazzolo, D., Friedrich, H., 2021. Macroplastics in rivers: present knowledge, issues and  
376 challenges. *Environ. Sci.: Processes Impacts* 23, 535–552. <https://doi.org/10.1039/D0EM00517G>
- 377 Antoni, V., Albizzati, C., Quintelier, C., 2020. Risques climatiques : six Français sur dix sont d'ores et déjà  
378 concernés. Rapport du Commissariat général du développement durable 4.
- 379 Battisti, C., 2021. Not only jackals in the cities and dolphins in the harbours: less optimism and more systems  
380 thinking is needed to understand the long-term effects of the COVID-19 lockdown. *Biodiversity* 1–5.  
381 <https://doi.org/10.1080/14888386.2021.2004226>
- 382 Bolingbroke, D., Ng, K.T.W., Surendran, S., 2018. On the nature of highway litter; a methodology and field  
383 study.
- 384 Borrelle, S.B., Ringma, J., Law, K.L., Monnahan, C.C., Lebreton, L., McGivern, A., Murphy, E., Jambeck, J.,  
385 Leonard, G.H., Hilleary, M.A., Eriksen, M., Possingham, H.P., De Frond, H., Gerber, L.R., Polidoro,  
386 B., Tahir, A., Bernard, M., Mallos, N., Barnes, M., Rochman, C.M., 2020. Predicted growth in plastic  
387 waste exceeds efforts to mitigate plastic pollution. *Science* 369, 1515–1518.  
388 <https://doi.org/10.1126/science.aba3656>
- 389 Burns & McDonnell, 2020. Pennsylvania Litter Research Study Final Report.
- 390 Castro-Jiménez, J., González-Fernández, D., Fornier, M., Schmidt, N., Sempéré, R., 2019. Macro-litter in  
391 surface waters from the Rhone River: Plastic pollution and loading to the NW Mediterranean Sea.  
392 *Marine Pollution Bulletin* 146, 60–66. <https://doi.org/10.1016/j.marpolbul.2019.05.067>
- 393 Chapman, C., Bomford, K., 2020. Litter in lockdown. A study of litter in the time of coronavirus. Full report  
394 from the Cleaner Counties Project for the county of Essex.
- 395 Crosti, R., Arcangeli, A., Campana, I., Paraboschi, M., González-Fernández, D., 2018. ‘Down to the river’:  
396 amount, composition, and economic sector of litter entering the marine compartment, through the Tiber  
397 river in the Western Mediterranean Sea. *Rendiconti Lincei. Scienze Fisiche e Naturali* 29, 859–866.  
398 <https://doi.org/10.1007/s12210-018-0747-y>
- 399 Directive (EU) 2019/904 of the European Parliament and of the Council of 5 June 2019 on the reduction of the  
400 impact of certain plastic products on the environment. *Official Journal of the European Union* L 155.
- 401 Edelson, M., Håbesland, D., Traldi, R., 2021. Uncertainties in global estimates of plastic waste highlight the  
402 need for monitoring frameworks. *Marine Pollution Bulletin* 171, 112720.  
403 <https://doi.org/10.1016/j.marpolbul.2021.112720>
- 404 Environmental Resources Planning, L., 2020. 2019 Texas Litter Survey. A Survey of Litter at 253 Sites  
405 throughout the State of Texas Conducted for GDC Marketing and Ideation. Don't mess with Texas final  
406 report.
- 407 Forbes, G.J., 2009. Reducing Litter on Roadsides, in: National Academies Press.
- 408 González-Fernández, D., Cózar, A., Hanke, G., Viejo, J., Morales-Caselles, C., Bakiu, R., Barceló, D., Bessa, F.,  
409 Bruge, A., Cabrera, M., Castro-Jiménez, J., Constant, M., Crosti, R., Galletti, Y., Kideys, A.E.,  
410 Machitadze, N., Pereira de Brito, J., Pogojeva, M., Ratola, N., Rigueira, J., Rojo-Nieto, E., Savenko, O.,  
411 Schöneich-Argent, R.I., Siedlewicz, G., Suaria, G., Tourgeli, M., 2021. Floating macrolitter leaked  
412 from Europe into the ocean. *Nature Sustainability* 4, 474–483. <https://doi.org/10.1038/s41893-021-00722-6>
- 413 Heinrich Böll Stiftung, La Fabrique Ecologique, Break Free From Plastic, 2020. Atlas du Plastique. Faits et  
414 chiffres sur le monde des polymères synthétiques.
- 415 Jambeck, J.R., Geyer, R., Wilcox, C., Siegler, T.R., Perryman, M., Andrady, A., Narayan, R., Law, K.L., 2015.  
416 Plastic waste inputs from land into the ocean. *Science* 347, 768–771.  
417 <https://doi.org/10.1126/science.1260352>
- 418 Keep America Beautiful, 2021. Keep America Beautiful 2020 National Litter Study Summary Report.
- 419 Lechthaler, S., Waldschlager, K., Stauch, G., Schüttrumpf, H., 2020. The Way of Macroplastic through the  
420 Environment. *Environments* 7, 73. <https://doi.org/10.3390/environments7100073>
- 421 MSFD Technical Group on Marine Litter, 2013. Guidance on monitoring of marine litter in European seas.  
422 Publications Office, LU.
- 423 Nowakhtar, N., 2016. 2016 TN Statewide Litter Study. Results Web-Exchange from nFront Consulting LLC.
- 424 Pietz, O., Augenstein, M., Georgakakos, C.B., Singh, K., McDonald, M., Walter, M.T., 2021. Macroplastic  
425 accumulation in roadside ditches of New York State's Finger Lakes region (USA) across land uses and  
426



427 the COVID-19 pandemic. *Journal of Environmental Management* 298, 113524.  
428 <https://doi.org/10.1016/j.jenvman.2021.113524>

429 PlasticsEurope, 2019. *Plastics - the Facts 2019. An analysis of European plastics production, demand and waste*  
430 *data*.

431 Poeta, G., Conti, L., Malavasi, M., Battisti, C., Acosta, A.T.R., 2016. Beach litter occurrence in sandy littorals:  
432 The potential role of urban areas, rivers and beach users in central Italy. *Estuarine, Coastal and Shelf*  
433 *Science* 181, 231–237. <https://doi.org/10.1016/j.ecss.2016.08.041>

434 Queensland Department of Environment and Heritage Protection, 2016. *Love Queensland. Let's keep it clean.*  
435 *South West Region Roadside Litter Prevention Pilot Project*.

436 Robertson, A., Armitage, N., Zuidgeest, M.H.P., 2019. Stormwater runoff quality on an urban highway in South  
437 Africa. *Journal of the South African Institution of Civil Engineering* 61. [https://doi.org/10.17159/2309-](https://doi.org/10.17159/2309-8775/2019/v61n2a5)  
438 [8775/2019/v61n2a5](https://doi.org/10.17159/2309-8775/2019/v61n2a5)

439 Schirinzi, G.F., Köck-Schulmeyer, M., Cabrera, M., González-Fernández, D., Hanke, G., Farré, M., Barceló, D.,  
440 2020. Riverine anthropogenic litter load to the Mediterranean Sea near the metropolitan area of  
441 Barcelona, Spain. *Science of The Total Environment* 714, 136807.  
442 <https://doi.org/10.1016/j.scitotenv.2020.136807>

443 Schmidt, C., Krauth, T., Wagner, S., 2017. Export of Plastic Debris by Rivers into the Sea. *Environmental*  
444 *Science & Technology* 51, 12246–12253. <https://doi.org/10.1021/acs.est.7b02368>

445 Schöneich-Argent, R.I., Dau, K., Freund, H., 2021. Corrigendum to “Wasting the North Sea? – A field-based  
446 assessment of anthropogenic macrolitter loads and emission rates of three German tributaries” [*Environ.*  
447 *Pollut.* 263 (Part B) (August 2020) 114367]. *Environmental Pollution* 287, 117235.  
448 <https://doi.org/10.1016/j.envpol.2021.117235>

449 Schöneich-Argent, R.I., Dau, K., Freund, H., 2020. Wasting the North Sea? – A field-based assessment of  
450 anthropogenic macrolitter loads and emission rates of three German tributaries. *Environmental*  
451 *Pollution* 263, 114367. <https://doi.org/10.1016/j.envpol.2020.114367>

452 Schultz, P.W., Bator, R.J., Large, L.B., Bruni, C.M., Tabanico, J.J., 2013. Littering in Context: Personal and  
453 Environmental Predictors of Littering Behavior. *Environment and Behavior* 45, 35–59.  
454 <https://doi.org/10.1177/0013916511412179>

455 Spearman, C., 1904. The proof and measurement of association between two things. *The American Journal of*  
456 *Psychology* 15, 72–101.

457 Thevenon, F., Carroll, C., Sousa, J. (Eds.), 2014. *Plastic debris in the ocean: the characterization of marine*  
458 *plastics and their environmental impacts, situation analysis report*. International Union for Conservation  
459 of Nature. <https://doi.org/10.2305/IUCN.CH.2014.03.en>

460 Tramoy, R., Blin, E., Poitou, I., Noûs, C., Tassin, B., Gasperi, J., 2022a. Riverine litter in a small urban river in  
461 Marseille, France: Plastic load and management challenges. *Waste Management* 140, 154–163.  
462 <https://doi.org/10.1016/j.wasman.2022.01.015>

463 Tramoy, R., Ledieu, L., Ricordel, S., Astrié, D., Tassin, B., Gasperi, J., 2022b. Macrolitter dataset from a highly  
464 frequented roadway in Nantes, France.

465 Tramoy, R., Gasperi, J., Dris, R., Colasse, L., Fisson, C., Sananes, S., Rocher, V., Tassin, B., 2019. Assessment  
466 of the Plastic Inputs From the Seine Basin to the Sea Using Statistical and Field Approaches. *Frontiers*  
467 *in Marine Science* 6, 151. <https://doi.org/10.3389/fmars.2019.00151>

468 Tramoy, R., Ledieu, L., Ricordel, S., Astrié, D., Tassin, B., Gasperi, J., 2021. Macrolitter along a highly  
469 frequented roadway. *Mendeley Data*. <https://doi.org/10.17632/t6ryv6crjd.1>

470 Treilles, R., Gasperi, J., Saad, M., Tramoy, R., Breton, J., Rabier, A., Tassin, B., 2021. Abundance, composition  
471 and fluxes of plastic debris and other macrolitter in urban runoff in a suburban catchment of Greater  
472 Paris. *Water Research* 192, 116847. <https://doi.org/10.1016/j.watres.2021.116847>

473 United Nations Environment Programme, 2021. *Addressing Single-use Plastic Products Pollution Using a Life*  
474 *Cycle Approach*. Nairobi.

475 van Emmerik, T., Kieu-Le, T.-C., Loozen, M., van Oeveren, K., Strady, E., Bui, X.-T., Egger, M., Gasperi, J.,  
476 Lebreton, L., Nguyen, P.-D., Schwarz, A., Slat, B., Tassin, B., 2018. A Methodology to Characterize  
477 Riverine Macroplastic Emission Into the Ocean. *Frontiers in Marine Science* 5.  
478 <https://doi.org/10.3389/fmars.2018.00372>

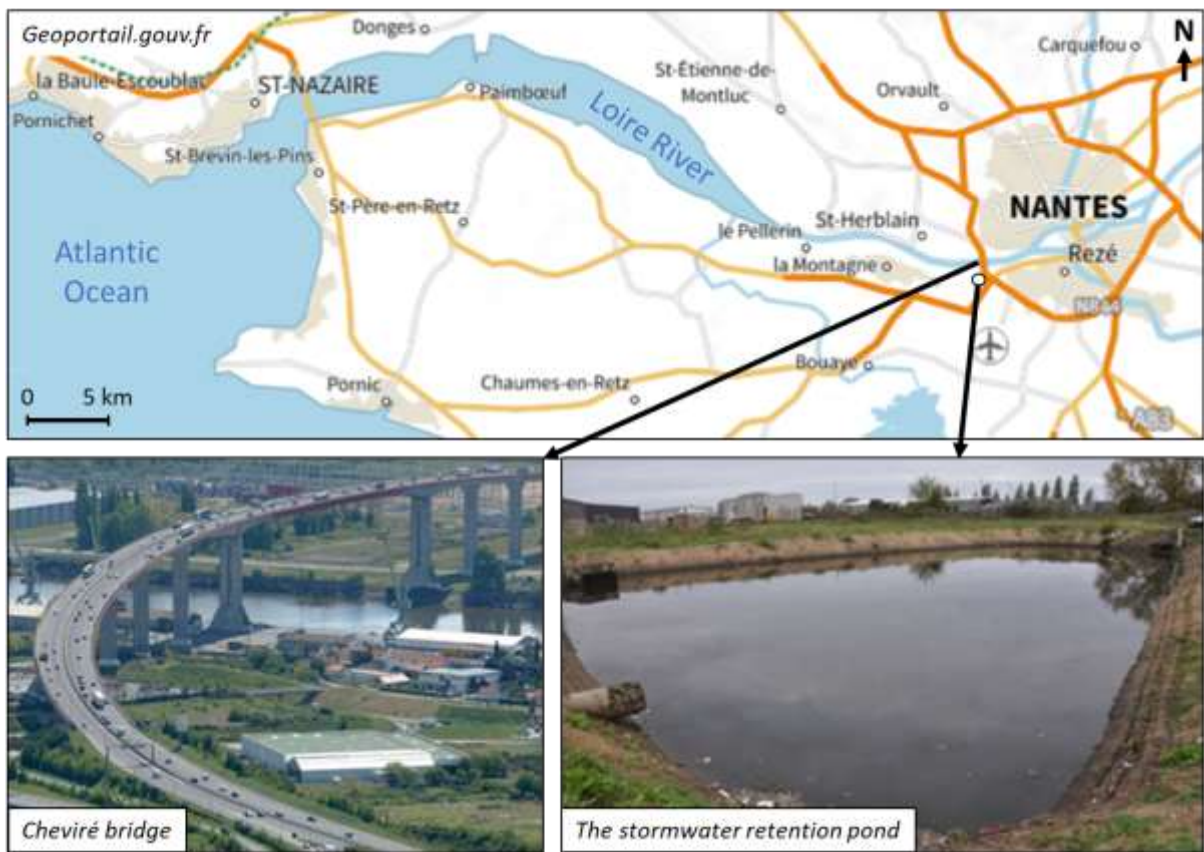
479 van Emmerik, T., Roebroek, C., de Winter, W., Vriend, P., Boonstra, M., Hougee, M., 2020. Riverbank  
480 macrolitter in the Dutch Rhine–Meuse delta. *Environmental Research Letters* 15, 104087.  
481 <https://doi.org/10.1088/1748-9326/abb2c6>

482 van Emmerik, T., Schwarz, A., 2020. Plastic debris in rivers. *WIREs Water* 7, e1398.  
483 <https://doi.org/10.1002/wat2.1398>

484 Vinci Autoroutes, 2021. *Dossier de presse : enquête et campagne de sensibilisation de la fondation Vinci*  
485 *Autoroutes*.

486 Vriend, P., van Calcar, C., Kooi, M., Landman, H., Pikaar, R., van Emmerik, T., 2020. Rapid Assessment of  
487 Floating Macroplastic Transport in the Rhine. *Frontiers in Marine Science* 7, 10.  
488 <https://doi.org/10.3389/fmars.2020.00010>  
489 Ward, C.P., Reddy, C.M., 2020. Opinion: We need better data about the environmental persistence of plastic  
490 goods. *PNAS* 117, 14618–14621. <https://doi.org/10.1073/pnas.2008009117>  
491 Watt, E., Picard, M., Maldonado, B., Abdelwahab, M.A., Mielewski, D.F., Drzal, L.T., Misra, M., Mohanty,  
492 A.K., 2021. Ocean plastics: environmental implications and potential routes for mitigation – a  
493 perspective. *RSC Advances* 11, 21447–21462. <https://doi.org/10.1039/D1RA00353D>  
494 Weideman, E.A., Perold, V., Arnold, G., Ryan, P.G., 2020. Quantifying changes in litter loads in urban  
495 stormwater run-off from Cape Town, South Africa, over the last two decades. *Science of The Total*  
496 *Environment* 724, 138310. <https://doi.org/10.1016/j.scitotenv.2020.138310>  
497 Windsor, F.M., Durance, I., Horton, A.A., Thompson, R.C., Tyler, C.R., Ormerod, S.J., 2019. A catchment-scale  
498 perspective of plastic pollution. *Global Change Biology* 25, 1207–1221.  
499 <https://doi.org/10.1111/gcb.14572>  
500

501



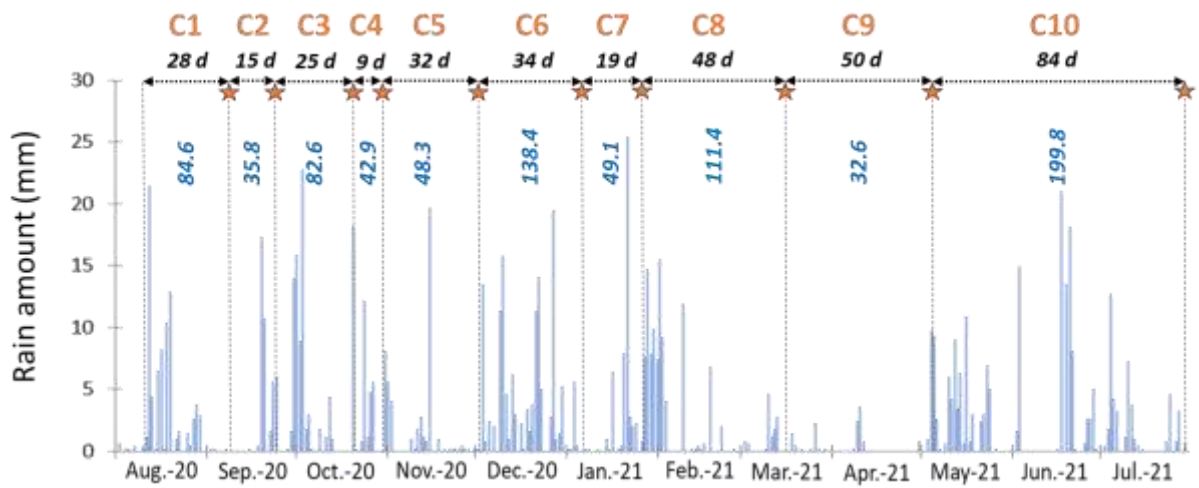
502

503 *Figure 1: Location of the Cheviré bridge in Nantes (Lat. 47.1849; Long. 1.6144) and its stormwater retention*

504 *pond where macrolitter were collected during one year. (Tramoy et al., 2022b)*

505

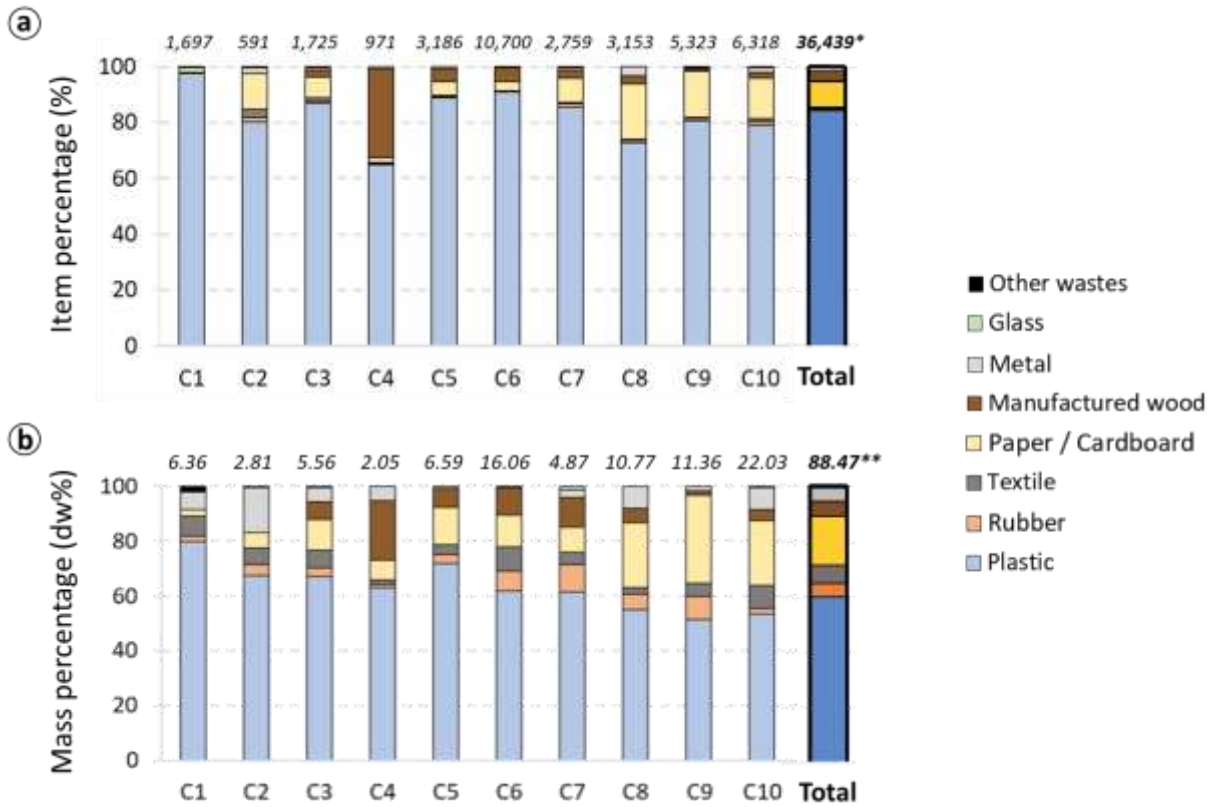
506



507

508 *Figure 2: Sampling (orange stars) and macrolitter accumulation periods (black arrows) for the ten campaigns*  
509 *(C1 to C10) according to the rain amount (in mm per day). An initial cleaning was performed the 10<sup>th</sup> of August*  
510 *2020 but no sample was collected. Total durations (in days noted d) and total rain amounts ([https://prevision-](https://prevision-meteo.ch/)*  
511 *meteo.ch/; Tramoy et al., 2021) for each campaign are indicated (in black and blue, respectively).*

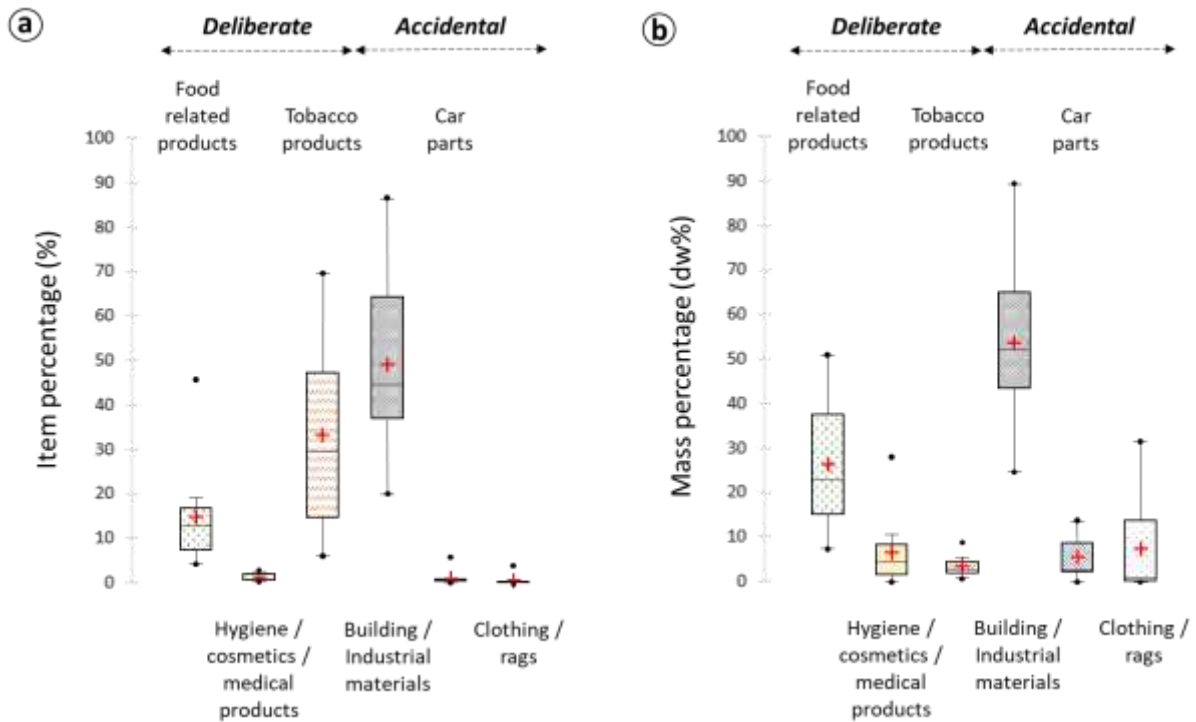
512



513

514 *Figure 3: a) Percentages of items and b) by dry weight (dw%) of the different categories of materials sampled*  
 515 *during the ten campaigns (C1 to C10) and during the total period of sampling (Total). a) \*The total number of*  
 516 *items. b) \*\*The total masses weighted in kg.*

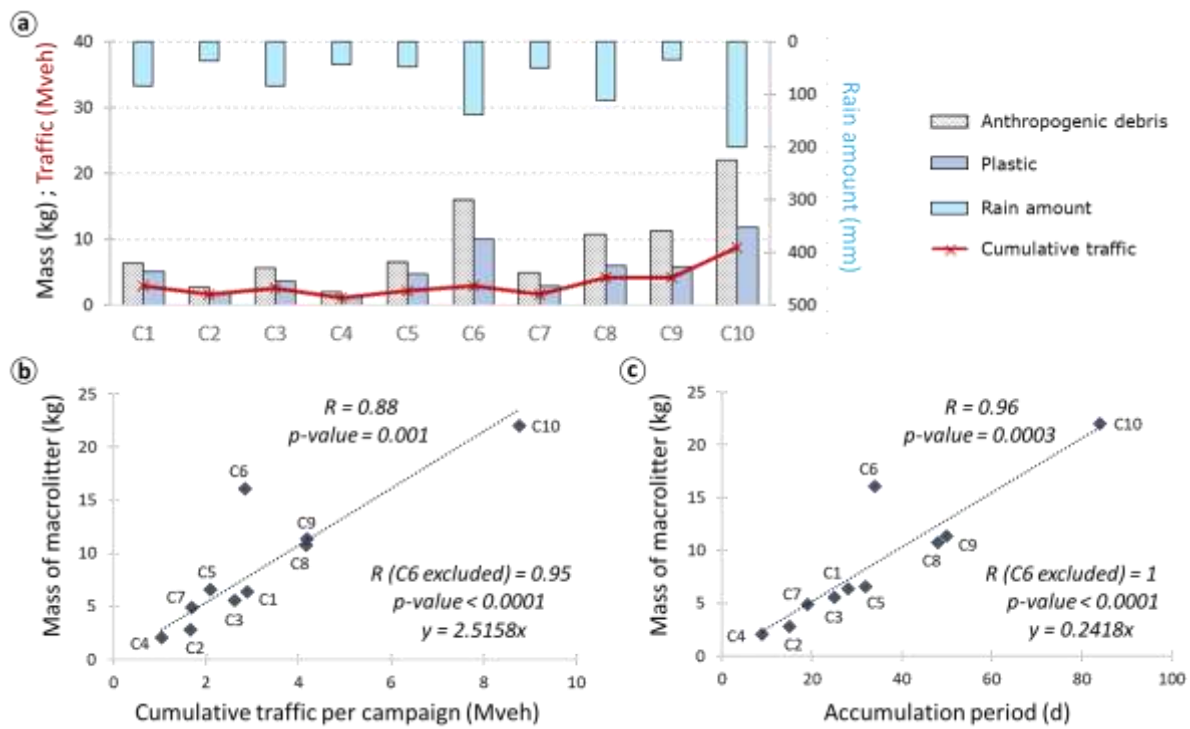
517



518

519 *Figure 4: Boxplots representing the variability (first quartile, third quartile and median; black points: maximum*  
 520 *and minimum; vertical bars: 1.5 times the interquartile range) and the mean percentages (red crosses) of items*  
 521 *a) by count and b) dry weight (dw%) during the ten campaigns according to their uses and economic sectors.*  
 522 *Food related products (n = 25 parent codes (24%)), cosmetics/medical products (n = 11 (10%)) and tobacco*  
 523 *products (n = 4 (4%)) are considered to result from deliberate littering. Building/industrial materials (n = 15*  
 524 *(14%), vehicle debris (n = 1 (1%)) and clothes/textile (n = 1 (1%)) are considered to result from accidental*  
 525 *littering.*

526



527

528 *Figure 5: a) Total masses (in kg) of macrolitter and plastic items according to the rain amount (in mm) and to*  
 529 *the cumulative traffic (in millions of vehicles). The correlations of total masses weighted with both b) the*  
 530 *cumulative traffic per campaign (in millions of vehicles) and c) the macrolitter accumulation period (in days).*  
 531 *The Spearman correlation coefficients (R), the p-values including and excluding C6 and the correlation*  
 532 *equations are indicated.*

533

534 *Table 1: Percentages of deliberate and accidental leaks in the masses collected during each campaign (C1 to*  
 535 *C10). Median percentages and interquartile range (IR) excluding C6 are also indicated.*

	<b>C1</b>	<b>C2</b>	<b>C3</b>	<b>C4</b>	<b>C5</b>	<b>C6</b>	<b>C7</b>	<b>C8</b>	<b>C9</b>	<b>C10</b>	<b>Median</b>	<b>IR</b>
<b>Deliberate</b>	34.3	51.0	40.1	42.4	32.7	9.2	51.8	58.0	25.5	20.4	37.2	±21.5
<b>Accidental</b>	65.7	49.0	59.9	57.6	67.3	90.8	48.2	42.0	74.5	79.6	62.8	±21.5

536

537

538

539 *Table 2: Loads (in kg/yr) and densities (in kg/yr/km and kg/yr/ha) of anthropogenic debris and plastic items extrapolated*  
 540 *with (i) the correlation equation between the masses weighted and the accumulation periods (in black) and (ii) with the total*  
 541 *masses collected during this survey (in orange).*

	Loads (kg/yr)	Density (kg/yr/km)	Density (kg/yr/ha)
Anthropogenic debris	<b>88.3</b>	<b>110.4</b>	<b>42.8</b>
	93.9	117.4	45.5
Plastics	<b>50.0</b>	<b>62.5</b>	<b>24.2</b>
	56.4	70.6	27.4

542

543



