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1 **Elucidating the vertical transport of microplastics in the water column:**
2 **a review of sampling methodologies and distributions**

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15 **Abstract:** There have been numerous studies that have investigated floating microplastics (MPs) in
16 surface water, yet little data are currently available regarding the vertical distribution in the water
17 column. This lack constrains our ability to comprehensively assess the ecological effects of MPs
18 and develop further policy controls. In this study, we reviewed current progress of sampling
19 methodologies, the distribution patterns, and the physiochemical properties of MPs throughout the
20 water column. Three sampling protocols were identified in this study: bulk, net and submersible
21 pump/in-situ sampling. In different regions, the vertical patterns of MPs in the water column varied
22 with depth, which is possibly related to the morphological characteristics, polymeric densities, and
23 biofouling of the MPs. The results of this review revealed that fibrous and fragmented MPs
24 comprised over 90% of the total MPs by quantity, of which fibrous MPs constituted the majority
25 (43%–100%). In addition, polyethylene terephthalate, polyamide, polyethylene, polyvinyl chloride,
26 and polypropylene have been widely identified in previous studies. To minimize the impact caused
27 by various sampling protocols, the use of a volume gradient trail experiment and a unified mesh

28 size of 60–100 μm for the initial concentration are recommended according to the results of this
29 review. Given the limited knowledge regarding the vertical transport of MPs in the water column,
30 harmonized sampling methods should first be developed. The mechanisms of this process can be
31 separately considered for different water bodies, such as freshwater systems, coastal waters, and
32 pelagic zones. The presence of these anthropogenic pollutants in the water column poses a threat to
33 the largest but most vulnerable habitats of life on earth, and hence they merit further investigation.

34 **Keywords:** water column; microplastics; sampling methodology; vertical distribution; transport

35

36 **1 Introduction**

37 The ubiquitous presence of microplastics (MPs) in the ocean (Cole et al., 2011; Lusher et al.,
38 2015), as well as in watersheds (Dris et al., 2015; Fan et al., 2019) worldwide, is now well
39 established. The global distribution of MPs within surface waters has been well demonstrated using
40 surface trawls in several studies (Moore et al., 2008; C3zar et al., 2014; C3zar et al., 2017; Isobe et
41 al., 2017). The floating stock of MPs in 2010 was estimated to be approximately 0.25 MT (Eriksen
42 et al. 2014), which is much smaller than the estimate of 4.8 to 12.7 MT for the amount of plastics
43 being released into the ocean (Jambeck et al., 2015). The large difference between the estimated
44 input and the observed MPs within the upper ocean imply that there are processes that alter the
45 distribution of MPs. Some studies have suggested that the missing portion is possibly attributable
46 to MPs sinking to the seafloor (Woodall et al., 2014; Courtene-Jones et al., 2020). Courtene-Jones
47 et al. (2020) reported the pervasive presence of MPs in a sediment core obtained from the Rockall
48 Trough, and a statistically significant historical accumulation was found.

49 The oceanic water column is the largest ecosystem on earth, and could potentially be a huge
50 reservoir of missing plastics from the earth's surface. However, to date, the vertical distribution of

51 MPs and the mechanisms involved during the sinking process are largely unknown. In addition,
52 these MPs could be intentionally or unintentionally ingested by aquatic organisms (Sussarellu et al,
53 2016; Galloway et al., 2017), potentially threatening billions of marine lives. Nevertheless, without
54 robust data on MP abundance in the water column, the impact on these species cannot be easily
55 ascertained.

56 This study reviewed the current progress of MPs research in the water column, and specifically,
57 this study focused on the vertical distribution from the surface to the deeper environment and related
58 sampling methods. However, the depth criteria for these studies have not been limited to hundreds
59 or thousands of meters, and only those that have primarily studied the vertical occurrence of MPs
60 in the aquatic environment were considered in this review. Furthermore, this review aimed to
61 identify the knowledge gaps in sampling methodologies, distribution patterns, and vertical transport
62 mechanisms from the surface water. Additionally, this review is expected to provide a
63 methodological introduction for subsequent studies to acquire representative samples and to
64 decipher the transport patterns of MPs into the deeper ecosystem.

65 **2. Database and search criteria**

66 The data used in this study were collected from the Web of Science on July 3rd, 2020. First, the
67 search string was defined as ((microplastic* OR plastics OR plastic microlitter OR synthetic
68 polymer) AND (water column OR water depth OR subsurface* OR water layers OR sampling depth
69 OR vertical distribution) AND (water)). All of the database ranging from 1990 to 2020 was searched
70 under the advanced research mode with “Topic” as the field tag. A total of 2,220 results were
71 preliminarily verified, and then most of the irrelevant records (N=1,372) according to targeted
72 research areas (environmental science ecology and oceanography) were excluded. The remaining

73 848 records was exported into a plain text format with the titles and abstracts.

74 These studies were further screened according to the content of the abstracts, and the selection
75 criteria were as follows: (1) They should be from peer-reviewed journals and original research
76 articles from field work. (2) For regional investigations, the depth intervals should be reported in
77 these studies, and at least two layers of water columns should be sampled. (3) Those with only one
78 sampling depth were not included in the spatial patterns analysis, except for the sampling
79 methodology summary. Overall, this review primarily focused on the sampling methodologies and
80 vertical distribution of MPs in the water columns. Eventually, a total of 31 references were identified.
81 These studies are summarized in Table 1, and the general geolocation of the sampled water columns
82 are mapped in Figure 1A.

83 **3. Sampling methodologies and sample analyses**

84 By categorizing by sampling methodology, these studies were generally divided into bulk-
85 water sampling (Bagaev et al., 2017; Bagaev et al., 2018; Cordova et al., 2018; Dai et al., 2018; Di
86 Mauro et al., 2017; Ding et al., 2019; Kanhai et al., 2018; Peng et al., 2018), net sampling (Lattin et
87 al., 2004; Lenaker et al., 2019;) and submersible pumps/in-situ sampling (Choy et al., 2019; Liu et
88 al., 2019; Song et al., 2018; Zobkov et al., 2019) (Fig.1).

89 **3.1 Bulk water sampling**

90 Typically, bulk water sampling allows for the collection of a defined volume of water at specific
91 water layers. This method offers an effective technique to sample bulk water samples during a
92 limited time duration, which could be useful in some restricted areas, especially in shallow waters.
93 The sampling devices primarily included a plexiglass water sampler (Ding et al., 2019), a Rosette
94 sampler system (CTD sampler) (Bagaev et al., 2017; Bagaev et al., 2018; Cordova et al., 2018; Dai

95 et al., 2018; Di Mauro et al., 2017; Kanhai et al., 2018), and the lander system (Peng et al., 2018).

96 For instance, by using the plexiglass water sampler (Fig.1C), Ding et al (2019) collected
97 seawater samples at depths of 1 m, 5 m, and 15 m in reef flats, North Reef, and the Yongle Atoll.
98 This device is particularly useful and convenient for MPs collection in shallow waters with
99 relatively low flow velocities, but would not be applicable to deeper aquatic environments.
100 Specifically, it is usually made of acrylic materials and can be fragile when subjected to intensified
101 external forces. In addition, the Rosette sampler system equipped with conductivity-temperature-
102 depth sensors (CTD) (Fig. 1B), was adopted to collect water samples at various depths in marginal
103 seas (Dai et al., 2018) and pelagic zones (Kanhai et al., 2018; Peng et al., 2018). It is typically
104 comprised of a set of Niskin bottles (8–12 L), a stainless-steel frame, and attached CTD sensors at
105 the bottom, which can sample water from over 6,800 m in depth. Moreover, Niskin bottles have also
106 been fitted on a lander system to collect bottom water near the seafloor (Fig.1G) (Peng et al., 2018).
107 Although it would be efficient to obtain MP samples at various layers of water samples for every
108 deployment, only limited volumes of seawater can be collected at each depth using Niskin bottles.

109 For the pretreatment and analysis of the MP samples, generally, most (N = 10) of the studies
110 (N = 13) reported that seawater samples collected using bulk sampling (plexiglass water sampler,
111 CTD sampler, and the lander system) were directly filtrated, especially for the smaller volume
112 collected samples (Table 1). MPs on the filters were retained and were visually examined using
113 stereomicroscopy. In addition, some researchers would first remove the organic matter in the
114 samples using digestive reagents and re-filtrate the MP samples before polymeric identification (Dai
115 et al., 2018).

116 3.2 Net sampling

117 A range of techniques with this mechanism have been used to collect water column MP samples,
118 which primarily included plankton trawls (Baini et al., 2018; Di Mauro et al., 2017; Doyle et al.,
119 2011; Lefebvre et al., 2019; Goldstein et al., 2013; Gorokhova, 2015; Güven et al., 2017; Oztekin
120 et al., 2015; Rowley et al., 2020), multi-net trawls (Kooi et al., 2016; Kukulka et al., 2012; Lattin et
121 al., 2004; Lenaker et al., 2019; Liedermann et al., 2018; Reisser et al., 2015), and multiple opening
122 and closing nets (Egger et al., 2020).

123 Vertical or oblique trawling was used to collect plankton samples in the water column, and this
124 was also applied to collect suspended MPs (Fig.1E) (Di Mauro et al., 2017; Frias et al., 2014;
125 Gorokhova, 2015). Gorokhova (2015) used a plankton net to investigate the seasonal variation of
126 MPs in the water column of the Baltic Sea down to 100 m in depth. This sampling protocol allowed
127 for the integration of the monitoring for MP pollution and the plankton community. However, this
128 method was unable to collect samples at specific water depths, and failed to differentiate the vertical
129 variation in the entire column. To attempt to overcome these challenges, there has been an effort to
130 simultaneously collect plastic debris in the upper aquatic environment using a multi-net trawl
131 (Fig.1F) (Kooi et al., 2016; Kukulka et al., 2012; Lattin et al., 2004; Lenaker et al., 2019;
132 Liedermann et al., 2018; Reisser et al., 2015). During the investigation, Lenaker et al. (2019)
133 deployed five neuston nets at depths ranging from 0.4 to 12.7 m in the Milwaukee River Basin and
134 synchronously sampled various layers of the water column. While this is a highly efficient sampling
135 method that would contribute a comparable result with previous studies that used surface trawls,
136 technical limitations only enable it to be applied in the upper aquatic environment. It would be
137 difficult to be applied at thousands of meters in depth.

138 Similar with the sample pretreatment used in the bulk sampling, for samples collected using

139 plankton nets (N=11, multiple opening and closing net has also been included) (Baini et al., 2018;
140 Di Mauro et al., 2017; Doyle et al., 2011; Goldstein et al., 2013; Gorokhova, 2015; Güven et al.,
141 2017; Lefebvre et al., 2019; Oztekin et al., 2015; Rowley et al., 2020), most of researchers visually
142 observed the MPs under stereomicroscopy in most of the studies (N=9). Only two studies performed
143 on the River Thames (Rowley et al., 2020) and in Turkish coastal waters (Güven et al., 2017)
144 digested organics to facilitate MP identification.

145

146 3.3 Submersible pumps and in-situ collection

147 The third sampling protocols for MPs in water columns included submerged pumps (Ng and
148 Obbard, 2006; Song et al., 2019; Zobkov et al., 2019), sediment traps (Ballent et al., 2016;
149 Reineccius et al., 2020), and in-situ filtration devices (Choy et al., 2019; Liu et al., 2019; Tekman
150 et al., 2020). In addition, an underway water intake system was also used to collect subsurface
151 seawaters at a specific depth (Lusher et al., 2015; Ryan et al., 2020).

152 Typically, submersible pumps have been used to quantify neustonic MPs in the surface water
153 (Zhao et al., 2014) (Fig.1D). Now, it has been also successfully applied these pumps to water
154 samples from substance waters in a coastal zone (Song et al., 2019; Zobkov et al., 2019). Using this
155 method, Song et al. (2019) sampled 100 L of water from various depths (0.20–58 m) at eight sites
156 in Korean coastal waters. In addition, a modified submerged pump by Zobkov et al. (2019) was also
157 used to collect water from the water column of the Baltic Sea. In their design, this device could
158 directly pump water from specific layers to the filters. Overall, this method could be more flexible
159 in the field than the CTD sampler and useful in epibenthic watersheds, especially for freshwater
160 systems and coastal waters. However, similar to the plexiglass water sampler, a sampling campaign

161 using submersible pumps could also be limited by hydraulic conditions, and sampling depths could
162 vary according to the sea state.

163 A further method used to sample MPs in the water column was in-situ collection, which can
164 directly filtrate or collect MPs samples from large volumes of water obtained from specific layers.
165 With this method, it is possible to obtain a concentrated sample from hundreds of cubic meters of
166 water at different depths down to thousands of meters (Choy et al., 2019; Liu et al., 2019; Tekman
167 et al., 2020). This could enable researchers to directly obtain a filter or net with MPs. This promising
168 technology enables the direct filtration of MPs from the surrounding water at high efficiency. Liu et
169 al. (2019) first used a plankton pump to *in-situ* filtrate the water column of the East China Sea
170 (Fig.1H), and the volume impact on the MP quantification was identified by filtrating the seawater
171 in the gradient. Choy et al. (2019) modified an *in-situ* filtration device and equipped it on an ROV
172 to collect MPs at nearshore and offshore sites of Monterey Bay, California (Fig.1I). In general, the
173 instrument used in the aforementioned two studies sampled exceptional large volumes at every
174 deployment according to the desired research plan, and compared with bulk sampling, it could
175 ensure data consistency with surface trawling. In addition, a recent study reported that an in-situ
176 filtration device was attached on a CTD sampler to filter MP samples from water columns near the
177 HAUSGARTEN observatory (Tekman et al., 2020). Nevertheless, these instruments could only
178 obtain one MP sample at a time, and therefore, they have to be retrieved when the sample campaign
179 is finished. Additional treatment or preparation (filter collection or washing process) needs to be
180 made before the next deployment.

181 In addition, sediment traps have also been used to collect MP samples from Humber Bay
182 (Ballent et al., 2016), and in this study that lasted six months, four cylinders of sediment traps were

183 collected from 2 m in depth above the lake bed. Recently, [Reineccius et al \(2020\)](#) placed sediment
184 traps at 2,000 and 3,000 m depth in the North Atlantic Subtropical gyre to monitor the deposition
185 flux of microfibers. These devices could directly capture the deposited MPs from the upper layers
186 of water columns. This allows for the assessment of the sinking behaviors and vertical flux of MPs.
187 However, these sampling instruments are typically fixed at a certain water depth, and the MP sinking
188 behaviors of every water layer are difficult to quantify.

189 A total of 8 studies used these methods (submersible pumps: N= 3; underway water intake
190 system: N= 2; in-situ filtration device: N= 3) to collect MP samples from water columns, and over
191 half of them (N=5) could directly verify the existence of MPs under stereomicroscopy without the
192 need to remove organic matter from the samples (Table. 1). In addition, of four studies that used
193 digestion pretreatment ([Liu et al., 2019](#); [Song et al., 2018](#); [Tekman et al., 2020](#); [Zobkov et al., 2019](#)),
194 [Song et \(2019\)](#) applied a density separation using a saturated NaCl solution to extract MP particles
195 from Korea coastal waters.

196 **4. Vertical distribution of MPs abundance**

197 Until now, few studies have considered the vertical pattern of MPs, and unharmonized
198 sampling methods have inevitably led to noncomparable results. In addition, regional differences
199 (e.g., emission sources, hydraulic conditions, and biological interactions) could also have hindered
200 an understanding of the vertical transport of MPs from the surface to deep ocean water. To facilitate
201 this comparison, in this review, the quantities of MP pollution in the water column were only
202 compared with studies that used the same sampling protocols within the similar waters categories
203 (e.g., freshwater systems, coastal waters, and pelagic zones) according their geolocation. Owing to
204 the differences in sampling methods and regions, the vertical distribution of MPs found in the studies

205 were separately analyzed.

206 **4.1 Freshwater systems**

207 Unlike coastal waters, the hydraulic conditions of freshwater systems are less dynamic, and a
208 freshwater catchment could be highly polluted due to the proximity to anthropogenic activities
209 (Wang et al., 2019). Typically, MPs were more abundant in the surface water once discharged from
210 an estuarine system, as Lenaker et al. (2019) described. An exponential decreasing trend of MPs
211 with water depth was found in freshwater systems, but no statistical difference was observed
212 (Lenaker et al., 2019). This pattern could possibly result from biofouling and biofilm on the MPs
213 that would contribute to sinking due to a density increase (Kooi et al., 2017). It was also found that
214 these MPs were sampled using multi-net trawls with a mesh size of 333 μm (Lenaker et al., 2019).
215 Therefore, the actual abundance of MPs could possibly be several orders of magnitude higher
216 because of progressive fragmentation (Cózar et al., 2014). In the current review, the general trend
217 of MPs in vertical direction was only focused on. It was also found that there was insufficient studies
218 of MPs in the water column of freshwater systems and their distribution mechanisms merit further
219 study.

220 **4.2 Coastal waters**

221 For the MP studies performed in coastal seas that used bulk sampling, a significant exponential
222 decrease between the water depth and the MP abundance was reported in the literature (Dai et al.,
223 2018; Song et al., 2018; Zobkov et al., 2019) ($R = 0.42$, $P = 2.08\text{E}^{-7} < 0.01$), which is similar to a
224 previous numerical model developed by Reisser et al. (2015). Reisser et al. (2015) sampled the top
225 6 m of the water column in the North Atlantic accumulation zone and also found an exponential
226 decrease in MP concentrations with increasing depth. However, a different pattern was observed

227 using an in-situ filtration technique (Choy et al., 2019; Liu et al., 2019), and a quadratic distribution
228 between the sampling depth and MP abundance was statistically revealed in coastal seas ($R = 0.76$,
229 $P = 0.02 < 0.05$). In summary, a higher MP content was found in the subsurface of the water column
230 by using in-situ filtration methods. The inconsistent distribution found using these two sampling
231 methods could be due to many factors such as sampling methods, water mass structure, MP pollution
232 sources, and the sinking velocity of MPs. Owing to the proximity to terrestrial sources in distance,
233 MP emissions could be assumed to be consistent, unless an accidental leakage occurred. Therefore,
234 this phenomenon could primarily result from the remaining factors. While it is logical that more
235 abundant MPs would be found in nearshore surface waters due to the proximity to sources (Song et
236 al., 2018), in fact, the studies revealed that a higher abundance of MPs could be detected in
237 subsurface waters in offshore areas. For example, Dai et al. (2018) collected samples from a total
238 of six water columns from the Bohai Sea and reported a relatively higher abundance of MPs in the
239 subsurface samples from locations further away from the coast. Indeed, similar findings were also
240 observed in the Baltic Sea, where Zobkov et al. (2019) found elevated MP abundances in the
241 subsurface layers, suggesting the importance of a density stratification impact on the vertical
242 distribution.

243 4.3 Pelagic zones

244 Until now, knowledge of the vertical distribution of MPs in the pelagic zone has been limited,
245 and few studies are currently available. Generally, floating MPs would be subjected to physical
246 mixing (Reisser et al., 2015) and biofouling (Goldstein et al., 2014), which would eventually sink
247 to deeper layers. In the surface water, the transport of MPs would be greatly influenced by wind and
248 waves (van Sebille et al., 2020), resulting in high frequency vertical displacements. While water

249 depth could be very critical in shaping the distribution patterns of MPs, the distance to the coast has
250 also been reported to have a relationship with their vertical distribution. Some studies have revealed
251 that higher quantities of MPs have indeed been detected nearshore, compared to observations near
252 the Arctic (Kanhai et al., 2018).

253 When sinking into deeper layers, MPs would be subjected to the structure of the water mass
254 and driven by global thermohaline circulation. In particular, the pycnocline, which could create a
255 density barrier, could possibly hinder the vertical transport of MPs and allow them to suspend for
256 extended times in haloclines or thermoclines. This hypothesis was preliminarily tested in the water
257 column of the Baltic Sea (Zobkov et al., 2019), and MPs were found to be temporally retained in
258 the density-gradient layers during the vertical transport.

259 After the long-term transport of MPs in the water column, partial MPs could eventually deposit
260 on the seafloor, and a higher abundance of MPs on the seafloor has been assumed to be the ultimate
261 sink for marine plastic debris (Bergmann et al., 2017; Woodall et al., 2014). It has been predicted
262 that a higher abundance of MPs would be both isolated in the upper water environment and in
263 bottom water near the seafloor (Kanhai et al., 2018; Peng et al., 2018). In addition, a recent study
264 indicated that bottom currents could also strongly control the movement of MPs at the seafloor and
265 regulate their vertical distribution (Kane et al., 2020). As a vital conveyor of nutrients and oxygen,
266 near-bed thermohaline currents could also play a key role in the ultimate fate of marine MPs.

267

268 **5. Morphological and chemical properties of MPs**

269 **5.1 Morphological characteristics**

270 Fiber, fragment, granule, foam, film, and microbead shaped MPs have been isolated from the

271 water column, and the detailed compositions are summarized in Table.2. These morphological
272 appearances of MPs in the water column have also been observed in many studies of surface waters
273 from inland freshwater systems, catchment runoff, coastal areas, and pelagic ocean areas (Desforges
274 et al., 2014; Free et al., 2014; Isobe et al., 2015; Gove et al., 2019). In the studies evaluated in this
275 review (Table 2), fibrous and fragmented MPs comprised over 90% of the total MPs by quantity, of
276 which fibrous MPs constituted the majority (43%–100%) over plastic fragments, with the exception
277 of results from the East China Sea and the Korean coastal waters, where a relatively higher
278 proportion of fragmented MPs were detected (Liu et al., 2019; Song et al., 2018). A possible
279 explanation for this phenomenon could be the joint effects of sampling protocols and regional
280 differences. Hence, this merits further study.

281 A previous study validated the shape effect on MPs that sink to a deeper environment, and fiber,
282 fragment, and sphere shaped MPs displayed a distinct sinking pattern (Khatmullina and Isachenko,
283 2017). However, fibrous MPs tended to sink in a direction perpendicular to their longest dimension,
284 and cylinder MPs exhibited some movements, such as, rotation, oscillation, and tumbling. Generally,
285 it was also found that were some patterns to the shape-based distribution throughout the water
286 column, and these are summarized in Table 2. Some studies reported a negative relationship between
287 MP size and sampling depth in coastal seas (Dai et al., 2018; Zobkov et al., 2019). For instance, Dai
288 et al. (2018) mentioned that the relative proportion of fibrous MPs was lower in subsurface waters
289 than in surface samples and the numerical proportion of MPs < 300 µm would increase with water
290 depth. This suggested a size-dependent removal mechanism. Similarly, during an investigation of
291 the Baltic Sea (Zobkov et al., 2019), MP size was found to exponentially decrease with depth.
292 However, significant shape variation has only been found in nearshore water columns, and shape

293 compositions along the vertical gradient did not vary significantly in the offshore area of the
294 Milwaukee River Basin (Lenaker et al., 2019). This difference could possibly be ascribed to the
295 stronger physical mixing in the coastal zone than in freshwater ecosystems, and biofouling could
296 primarily contribute to the removal of MPs from the surface in freshwater systems.

297 5.2 Polymer composition

298 An analysis of the polymeric types was performed in 17 of the studies (Baini et al., 2018; Choy
299 et al., 2019; Cordova et al., 2018; Dai et al., 2018; Di Mauro et al., 2017; Ding et al., 2019; Egger
300 et al., 2020; Kanhai et al., 2018; Lefebvre et al., 2019; Lenaker et al., 2019; Lusher et al., 2015; Ng
301 and Obbard, 2006; Peng et al., 2018; Rowley et al., 2020; Song et al., 2018; Tekman et al., 2020;
302 Zobkov et al., 2019), and a total of 37 polymer types were verified in the water column (Table.3).
303 PE, PP, PET, PA, and PVC MPs have been widely identified in previous studies, of which PET MPs
304 ranked first in quantity. Overall, the polymeric composition of MPs from the surface to the bottom
305 has been barely reported on, and most of the studies have only reported on the general composition
306 of all obtained MPs, regardless of sampling depth.

307 A recent investigation revealed the gradient distribution of polymers with depth, suggesting a
308 partial contribution of polymer density in the vertical transport in the water column (Lenaker et al.,
309 2019). This finding was consistent with a previous report on the seafloor (Woodall et al., 2014),
310 where negative buoyant MPs were speculated to sink eventually. In research of the Milwaukee River
311 Basin (Lenaker et al., 2019), the content of MPs with lower densities decreased with increasing
312 sampling depth, and higher density MPs (PA, PAN, PVAc, and PET) displayed the opposite trend.
313 Similarly, in the Bohai Sea, MPs with higher densities (e.g., PET and PVC) were found in the deeper
314 layers of the water column (Dai et al., 2018). However, during the analysis, they also found PE MPs,

315 which have a density less than water, in the benthic sediment, suggesting that the sinking mechanism
316 of MPs could be multifactorial. Additionally, the higher degradation on the surface of MPs from the
317 deeper layers was imaged (Dai et al., 2018), implying the important contribution of biofouling. This
318 biological process was observed using an in-situ feeding experiment by Katija et al. (2017). In this
319 study, MPs incorporated in fecal pellets of giant larvaceans quickly sank to the deeper environment.
320 Moreover, this density-dependence theory was also preliminarily confirmed by findings from
321 Korean coastal waters (Song et al., 2018), where researchers found that MPs with higher densities
322 would be typically detected in the subsurface of water columns. Interestingly, in this study, MPs
323 with PP and PE polymeric compositions also prevailed throughout the water column. While, in fact,
324 it is common for MPs with higher densities than water to quickly sink to deeper layers, there is also
325 an interesting fact that plastic debris with less densities prevail throughout the water column. A
326 density-dependent hypotheses could be useful to explain the fast sinking of MPs with higher
327 densities than water, yet little is known about the later process of how low-density MPs transport
328 into the deeper layers. Constrained by the available data, it can only be speculated that physical
329 mixing (Isobe et al., 2015; Reisser et al., 2015) could be significant to the removal of floating plastic
330 debris from surface waters. Physical mixing triggered by wind and waves was observed in a previous
331 study by Reisser et al. (2015), and small-sized plastic debris would be susceptible to this vertical
332 transport in the upper aquatic environment. However, the vertical transport of MPs in the water
333 column is not merely dependent on polymeric densities, and further implications due to MP shapes
334 and the water mass structure were also highlighted in a relevant study (Kowalski et al., 2016).

335

336 6. Outlook for following studies

337 6.1 Harmonized sampling methodology

338 While neustonic MPs have been well studied (Cózar et al., 2014; Isobe et al., 2019; Thompson
339 et al., 2004), knowledge of vertical transport in the water column is presently limited. To acquire
340 comparable data, a harmonized sampling methodology would be of great importance and needs to
341 be developed and studied. However, to date, various sampling methods (e.g., CTD samplers,
342 submerged pumps, multi-net trawls, in-situ filtration devices, and sediment traps) have been utilized,
343 and this inevitably leads to noncomparable results among studies. To date, several guidelines
344 regarding the sampling protocols of MPs in the water column have been mentioned (Cheshire et al.,
345 2009; GESAMP, 2019; Galgani et al., 2011; Masura et al., 2015), but only general instructions have
346 been provided, or it has been barely referred to. For instance, the UNEP/IOC guidelines primarily
347 focus on the sampling methodology of marine litters on beaches, surface waters, and the seafloor
348 (Cheshire et al., 2009), and trawling collection has been recommended for floating and benthic
349 litters. While in the guidelines developed by GESAMP (2019), a series of sampling instruments (i.e.,
350 plankton nets, submerged pumps) were listed. Unfortunately, efficiency validations of these
351 protocols have not been intensively evaluated. In addition, the impact of volume on MP
352 quantification has been reported in a recent study (Liu et al., 2019; Lusher et al., 2014), and a more
353 stable quantification would be obtained by using large-volume samples, which has been speculated
354 to be vital to accurately reveal the MP occurrence. Similarly, Tamminga et al. (2018) found that the
355 sample efficiencies of a manta trawl and bulk samples were not comparable, and a limited sample
356 volume is insufficient to represent an entire water mass. In addition, the mesh size of trawls could
357 be an unneglectable factor that would hinder the collection of representative samples (Hidalgo-Ruz
358 et al., 2012). It is acknowledged in this review that it would be a great challenge to implement a

359 unified sampling methodology among regional studies due to the availability and regional
360 differences of sampling instruments. Therefore, it is proposed to conduct a volume gradient
361 experiment prior to each investigation to reach the ideal volume of filtrated water, as described by
362 [Liu et al. \(2019\)](#), especially for bulk sampling and water samples collected using submersible pumps.
363 The primary reason for this trial experiment is to understand the heterogeneous distribution (both
364 temporal and spatial) of MPs in aquatic environments. To validate the sampling volume, [Lusher et
365 al. \(2014\)](#) collected 100 L, 250 L, 500 L, 1,000 L, and 2,000 L water samples using a submerged
366 pump and confirmed the ideal volume to be 2,000 L. This significant impact of the sampling volume
367 on MP quantification was also studied by [Liu et al. \(2019\)](#). They found that more stable results could
368 be obtained when the volume of filtrated water when using an in-situ filtration device was $>8 \text{ m}^3$.

369 To facilitate collection by bulk sampling, submersible pumps, and in-situ filtration, the use of
370 60–90 μm mesh size is also recommended in this review to obtain concentrated samples because 14
371 of 31 of the reviewed studies revealed that the size of isolated MPs are typically greater than 50 μm
372 (Table 1). In addition, a recent study also revealed the great importance of mesh size on MP
373 quantification, and a smaller size (100 μm) of the sampling trawls could lead to a ten-time higher
374 abundance of MPs as opposed to a net with 500 μm ([Lindeque et al., 2020](#)), suggesting the possible
375 underestimation in previous work that used a Manta trawl (330 μm). Nevertheless, in contrast, [Ryan
376 et al. \(2020\)](#) found that a mesh size of 20 μm –63 μm only had a slight impact on MP quantification
377 using bulk sampling. While smaller mesh size would ensure the capture ability of suspended MPs
378 in the water, blockages by zooplankton and algae could also occur, especially in freshwater
379 ecosystems and coastal waters, and therefore this should be carefully considered. These two studies
380 revealed important issues regarding the accurate quantification of MPs in the field, and a

381 combination of trawl sampling and bulk collection should be carefully considered in a future study.
382 Moreover, a unified pretreatment of water samples could also be necessary to obtain a robust and
383 replicable results, meriting further work and collaboration.

384 **6.2 Depletion mechanisms of plastic debris from surface waters**

385 Plastic debris depletion patterns from the surface remain unclear, but several hypotheses (i.e.,
386 physical and biological forces) for this process have been proposed (Cózar et al., 2014). This vertical
387 movement could result from the joint effects of hydrodynamics (i.e., tidal motion, Ekman pumping,
388 upwelling, downwelling, and turbulence-induced roll structures), plastic properties, and bio-
389 interactions, as van Sebille et al. (2020) summarized. In addition, the transport could also be
390 influenced by water stratification, especially in estuaries (Zhao et al., 2019).

391 For instance, the sinking of floating MPs was speculated to have a close relationship with
392 physical mixing by wind and waves in surface waters (Reisser et al., 2015), and the remaining
393 transport could be ascribed to progressive fragmentation, ingestion by aquatic organisms, and
394 biofouling (Andrady, 2011). In addition, these missing MPs could be also washed up onshore (Cózar
395 et al., 2014), but the quantitative inventory remains unknown. Another hypothesis could be size
396 selection depletion, where small-sized MPs from progressive fragmentation tend to sink faster. Size
397 dependence removal of floating plastic debris from the surface of an open ocean was addressed in
398 a previous investigation by Cózar et al. (2014). They speculated that progressive weathering would
399 contribute to the fast sinking of MPs < 1 mm into deeper environments. This morphological
400 contribution to the vertical transport was also highlighted by Khatmullina and Isachenko (2017),
401 and distinct sinking behaviors of fibrous, cylindrical, and spherical MPs were observed in their
402 experiment.

403 In addition, this floating plastic debris would be gradually colonized by fouling
404 microorganisms (Amaral-Zettler et al., 2020; Barnes, 2002), and the density would increase. This
405 would lead to a loss of buoyancy over time. Based on the dynamic model of biofilm formation, Kooi
406 et al. (2017) reported that the vertical transport of MPs could be related to MP density and size, and
407 the maximum MP content would be detected at intermediate depths. In addition, phytoplankton can
408 also facilitate the vertical displacement of MPs in the water column. In particular, algal aggregation
409 would constantly increase the density of MPs, driving the MPs into the deeper environment
410 (Lagarde et al., 2016; Long et al., 2015).

411 Another assumption was the accidental ingestion by aquatic organisms, which has been
412 observed in numerous species (Gove et al., 2019; Jâms et al., 2020; Sun et al., 2018). Ingested MPs
413 are temporally stored in the digestive tracts of organisms and transferred along the food-webs
414 (Nelms et al., 2018). In addition, MPs could be transported from the surface to the deeper layers
415 during the vertical migrations of species, and then egested with excrement. This aspect merits further
416 quantitative estimation.

417 **7. Conclusion**

418 Overall, various vertical patterns from the surface to the seafloor in different water bodies (i.e.,
419 freshwater systems, coastal waters, and pelagic zones) were found in this review, but their inner
420 mechanisms could possibly differ among regions. However, inconsistent sampling methodologies
421 inevitably hinder researchers from adequately comparing processes among regions. In addition, this
422 hinders an accurate estimate of the vertical transport of MPs from the upper aquatic environment.
423 Thus, in this review, a volume gradient experiment is recommended to obtain the ideal volume of
424 filtrated water before an investigation. In addition, a unified mesh size of 60–90 μm is suggested to

425 minimize the sample volume and mesh size impact on MP quantification. A combination of bulk
426 samples and net collection could be also be an effective method to reveal the sink patterns of MPs
427 from the surface water. In addition, although several hypotheses and lab-based experiments have
428 highlighted the contribution of morphological and polymeric density to the vertical transport,
429 insufficient data in the field continue to constrain the understanding of the realistic transport of MPs.
430 Given the ambiguity in the transport mechanisms, more field-based experiments should be
431 conducted to more thoroughly understand the environmental behaviors by using validated sampling
432 protocols. A separate consideration of transport processes in different habitats is suggested, and there
433 is a need to quantify the contribution of the potential drivers of vertical transport.

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441

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672 **Figure list:**

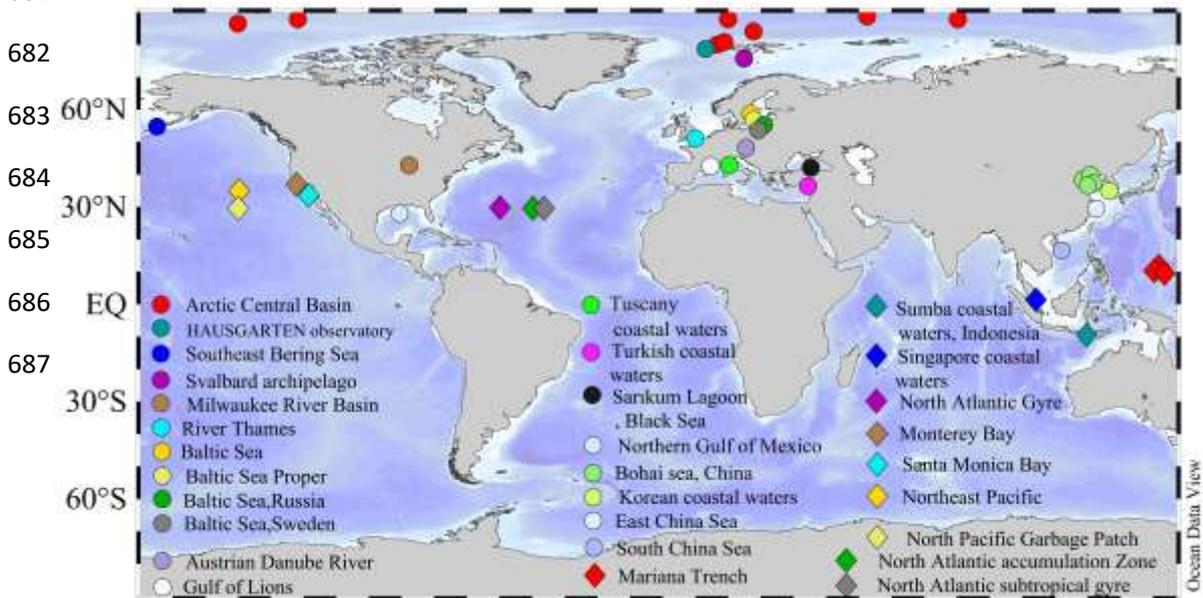
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674 **Fig.1 Geolocation of sampled water columns for MPs research (A).** Red dots indicate the
 675 geographical locations of sampling sites in collected literatures except for [Ryan et al, 2020](#) due to
 676 limited accessible information. **Sampling device used for collecting MPs in the water column (B:**
 677 **CTD sampler; C: plexiglass water sampler; D: submersible pump; E: plankton net; F: multi-**
 678 **net trawls; G: lander system; H: plankton pump; I: remotely operated vehicle (ROV)).**

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681 **A)**



Ocean Data View

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701 **Table list:**

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- Table.1 Sampling information of MPs in the water column from literatures
- Table.2 Characteristics summary of MPs in the water columns from literatures
- Table.3 Polymer type, its abbreviation, density of observed MPs in the water column from reference (N=17)

Table.1 Sampling information of MPs in the water column from literatures

Sampling regions	Methods	depth (m)	volume /sample(L)	Mesh size of nets ^a or filters (sieves) ^b (μm)	Samples pretreatment and polymer analysis	MPs size (mm)
South China Sea, China (Ding et al., 2019)	plexiglass water sampler	5 and 15	5	0.45 ^b	Direct filtration; μ-FT-IR spectrometer	0.02-0.33 (mostly) ^c
South China Sea, China (Ding et al., 2019)		10-40	5	0.45 ^b	Direct filtration; μ-FT-IR spectrometer	0.02-0.33 (mostly) ^c
Arctic Central Basin (Kanhai et al., 2018)	CTD sampler	8-4,369	7-48	250 ^b ; 1.20 ^b	Direct filtration; μ-FT-IR spectrometer	0.25-5.00
Mariana Trench		2,673-10,903	35-180	0.22 ^b ; 0.30 ^b	Direct filtration;	1.00-3.00

(Peng et al., 2018)				Raman spectroscopy	(mostly) ^c
Baltic Sea proper (Bagaev et al., 2017)	0.5-217.5	7.79-30	174 ^b	Direct filtration; Combination of visual identification and UV lamp	N/A ^d
Baltic Sea (Bagaev et al., 2018)	0-217.5	10 or 30	174 ^b	Direct filtration; Elastic property determination	N/A ^d
Bohai sea, China (Dai et al., 2018)	0-30	5	5 ^b ; 20 ^b	Concentrate the sample with 5 µm porosity filters and remove the organics prior to next filtration (20µm); µ-FT-IR spectrometer	0.10-3.00 (mostly) ^c
Sumba coastal waters, Indonesia (Cordova et al., 2018)	5-300	10	0.45 ^b	Direct filtration; FT-IR spectrometer	0.30-1.00 (mostly) ^c
Northern Gulf of Mexico (Di Mauro et al., 2017)	2.2-53.5	5	0.70 ^b	Direct filtration; FT-IR spectrometer	N/A ^d
Baltic Sea, Sweden (Gorokhova, 2015)	0-100	6,200-9,200	90 ^a	Direct observation; visual identification	0.05-0.30 (mostly) ^c
Sarikum Lagoon, Black Sea (Oztekin et al., 2015)	0-30	N/A ^d	300 ^a ; 1.20 ^b	Direct filtration; No polymeric identification	N/A ^d
River Thames (Rowley et al., 2020)	0-2	N/A ^d	250 ^a ; 32-1,000 ^b	Organics removal prior to direct observation; FT-IR spectrometer	0.03-5.00
Tuscany coastal waters, Mediterranean Sea (Baini et al., 2018)	2-120	500-30,000	200 ^a	Direct observation; FT-IR spectrometer	1-2.5 (mostly) ^c
Turkish coastal waters, Mediterranean Sea (Güven et al., 2017)	0-55	N/A ^d	200 ^a ; 26 ^b	Organics removal prior to direct observation; FT-IR spectrometer	0.1-2.5 (mostly) ^c
Gulf of Lions (Lefebvre et al., 2019)	0-100	N/A ^d	200 ^a	Direct observation; FT-IR spectrometer	0.24-4.93
Northern Gulf of Mexico (Di Mauro et al., 2017)	0-15	12,800- 64,100	335 ^a ; 50 ^b	Direct observation; FT-IR spectrometer	N/A ^d
Southeast Bering Sea (Doyle et al., 2011)	0-212	N/A ^d	505 ^a	Direct observation; FT-IR spectrometer	N/A ^d
Northeast Pacific (Goldstein et al., 2013)	0-210	N/A ^d	202 ^a	Direct observation; FT-IR spectrometer	N/A ^d
Santa Monica Bay multi-net	0-14.80	N/A ^d	333 ^a	Freshwater floatation;	2.80-4.75

(Lattin et al., 2004)	trawls					No polymeric identification	(mostly) ^c
Milwaukee River Basin (Lenaker et al., 2019)		0-15.50	N/A ^d	333 ^a ; 355-4,750 ^b		Organics removal prior to the filtration; FTIR spectrometer and py-GCMS	0.36-1.00 (mostly) ^c
North Atlantic accumulation Zone (Kooi et al., 2016)		0-5.5	N/A ^d	330 ^a ; 500-5,000 ^b		saltwater floatation; No polymeric identification	0.50-5.00
North Atlantic subtropical gyre (Kukulka et al., 2012)		5-20	N/A ^d	N/A ^d		N/A ^d	N/A ^d
North Atlantic Gyre (Reisser et al., 2015)		0-5	N/A ^d	150 ^a ;		seawater floatation; No polymeric identification	0.50-5.00
Austrian Danube River (Liedermann et al., 2018)		N/A ^d	N/A ^d	500 ^a		NaCl solution floatation prior to the refiltration; FT-IR spectrometer	N/A ^d
North Pacific Garbage Patch (Egger et al., 2020)	Multiple Opening and Closing Net	0-2,002	136,000-5,039,000	333 ^a ; 500-15,000 ^b		Direct observation; Raman spectroscopy	N/A ^d
Svalbard archipelago, Norway (Lusher et al., 2015)		0 (manta trawl) and 6	2,000	250 ^b ; 1.2 ^b		Direct filtration; FT-IR spectrometer	0.25-5.00
Southern Ocean, Atlantic Ocean, Indian Ocean and Mediterranean Sea (Ryan et al., 2020)	underway water intake system	0 (metal bucket) and 5	10-20	0.70 ^b		Direct filtration; No polymeric identification	N/A ^d
Singapore coastal waters (Ng and Obbard, 2006)		0 (Rotating drum sampler) ^e and 1	10	1.6 ^b		Direct filtration; FT-IR spectrometer	N/A ^d
Baltic Sea, Russia (Zobkov et al., 2019)	submersible pump	0.5-91	2,500-3,500	174 ^b		Organics removal prior to the refiltration (174 μ m); μ -Raman spectroscopy	0.17-1.00 (mostly) ^c
Korean coastal waters (Song et al., 2018)		3-58	100	20 ^b ; 5 ^b		NaCl solution floatation prior to the refiltration; μ -FT-IR spectrometer	0.02-5.00
East China Sea (Liu et al., 2019)	In-situ filtration device	4	1,000-16,000	60 ^a ; 1.60 ^b		Organics removal prior to the filtration; μ -FT-IR spectrometer	N/A ^d
Monterey Bay		5-1,000	1,007-2,378	100 ^b		Direct observation;	N/A ^d

<hr/>				Raman spectroscopy	
<hr/>				Organics removal prior	
(Choy et al., 2019)				to the filtration;	0.01-0.15
HAUSGARTEN	1-5,350	218-561	32 ^b	μ-FT-IR spectrometer	
observatory					
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(Tekman et al., 2020)					

- 714 a: mesh size of net used in the reference.
- 715 b: mesh size of filter or sieve used in filtering process.
- 716 c: only size range of MPs was presented in the literature.
- 717 d: N/A represented no available information.
- 718 e: during the investigation in Singapore coastal waters, Ng and Obbard (2006) sampled 50-60 μm depth in the surface
- 719 using a rotating drum sampler and it could be considered as surface sampling due to the proximity to the air-sea
- 720 interaction surface.

Table.2 Characteristics summary of MPs in the water columns from literatures

Region division	Study area	Sampling methods	Shape composition of MPs						Major findings
			Fiber	Fragment	Granule	Foam	Film	Microbead	
Freshwater system	River Thames	Bulk sampling	Exclude ^b	Detect ^b	Detect ^b	-	Detect ^b	Detect ^b	The abundance of MPs varied with sampling month, location and depth
	Milwaukee River Basin	Net sampling	89%	8%	0.40%	1%	2%	-	Significant variation of shape composition was not found offshore
	Austrian Danube River	Net sampling	-	-	-	-	-	-	A new methodology for MPs in the water column was established; 500 µm mesh size of net was recommended
Coastal waters	Bohai sea, China	Bulk sampling	91%	9%	-	-	-	-	Numerical proportion of fibrous MPs is lower than surface water; Content of MPs < 300 µm increase with depth.
	South China Sea, China	Bulk sampling	80%	13%	5%	-	2%	-	The number of MPs would decrease with depth, and peak at the subsurface
	Baltic Sea proper	Bulk sampling	Detect ^b	Detect ^b	-	-	Detect ^b	-	More abundant fibrous MPs would be found near surface and bottom water than intermediate water
	Sumba coastal waters, Indonesia	Bulk sampling	45%	-	36%	-	-	-	Most of MPs was found above the thermocline.
	Northern Gulf of Mexico	Bulk sampling	Detect ^b	Detect ^b				Detect ^b	No significant relationship between MPs abundance and sampling was

								observed
Baltic Sea, Sweden	Net sampling	-	-	-	-	-	-	The abundance of MP in deeper layers was found to be positively influenced by zooplankton abundance in the upper layers
Sarikum Lagoon, Black Sea	Net sampling	Detect ^b	Detect ^b	-	-	-	-	The highest content of MPs would be found in subsurface samples
Tuscany coastal waters, Mediterranean Sea	Net sampling	29%	62%	-	-	-	Detect	Smaller MPs could be easier to sink; MPs abundance would decrease with depth
Turkish coastal waters, Mediterranean Sea	Net sampling	9%	33%	-	-	-	-	PS MPs was not detected in water column samples
Gulf of Lions	Net sampling	100%	-	-	-	-	-	The size range of MPs in the water column is similar with ingested MPs by fish
Northern Gulf of Mexico	Net sampling	Detect ^b	Detect ^b	-	-	-	-	Several order higher abundances of MPs were found in bulk samples than net sampling;
Southeast Bering Sea	Net sampling	Detect ^b	Detect ^b	Detect ^b	-	-	-	MPs was only observed in subsurface sample during winter
Santa Monica Bay	Net sampling	Detect ^b	Detect ^b	Detect ^b	-	-	-	More abundant MPs was found in the surface water and near the bottom than in intermediate water
Korean coastal waters	Submersible pump	18%	81%	-	-	-	1%	MPs prevailed throughout the water column regardless of polymer density; Biological interaction would

									also contribute to downward transport besides physical mixing.
	Singapore coastal waters	Submersible pump				N/A ^a			PE MPs was more abundant in subsurface layers
	Baltic Sea, Russia	Submersible pump	90%	2%	-	-	8%		MPs size was found to be exponential decrease with depth; MPs offshore distribution would be determined by pycnocline.
	Svalbard archipelago, Norway	underway water intake system	95%	4.9%	-	-	<0.1%	-	The results by net sampling cannot be compared with data by underway water intake system
	East China Sea	In-situ filtration	43%	57%	-	-	-	-	Sampling volume would greatly influence MPs quantification in the water column and ample volume of filtrated water would ensure the reliability of dataset.
	HAUSGARTEN observatory	In-situ filtration					N/A ^a		Highest content of MPs was found in the subsurface water; a positive relationship between MPs size and particulate carbon was revealed
	Monterey Bay	In-situ filtration					N/A ^a		Highest abundance of MPs was found just below the mixed layers; Deep sea water column could be vital pool of marine MPs
Pelagic zone	Arctic Central Basin	Bulk sampling	96%	4%	-	-	-	-	No significant correlation was found between MPs content and sampling

									depth.
Mariana Trench	Bulk sampling	Majority ^b	A little ^b	A little ^b	-	-	-		The hadal zone could be the largest sink of marine plastic debris; Linear relationship between MPs abundance and depth
North Atlantic accumulation zone	Net sampling	Detect ^b	Detect ^b	Detect ^b	-	-	-		Numerical abundance and mass concentration of MPs would exponentially decrease with depth
North Atlantic subtropical gyre	Net sampling							N/A ^a	Vertical transport of plastic debris could mainly result from wind-driven mixing
North Atlantic Gyre	Net sampling	Detect ^b	Most ^b	Detect ^b	Detect ^b	-	-		Mass concentration of plastic debris would exponentially decrease with depth; sink rate have a close relationship with sea state.
North Pacific Garbage Patch	Net sampling	Detect ^b	Detect ^b	-	-	-	-		Mass concentration of plastic fragment decrease with depth
Northeast Pacific	Net sampling	-	-	-	-	-	-		Most of MPs was observed on surface water

722 a: N/A indicated no available information.

723 b: Numerical proportion was not clearly presented in the study.

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727 **Table.3 Polymer type, its abbreviation, density of observed MPs in the water column from**
 728 **reference (N=17)**

Polymer types	Abbreviation	Reference density (g/cm ³) ^a	Number of studies (N)
polyethylene	PE	0.92-0.96	15
polypropylene	PP	0.90-0.92	13
polyethylene terephthalate	PET	1.34	12
polyamide	PA	1.02-1.14	11
polyvinyl chloride	PVC	1.38-1.41	11
polystyrene	PS	1.05	10
poly (methyl methacrylate)	PMMA	1.17-1.20	6
acrylonitrile butadiene styrene	ABS	1.04-1.06	3
polyacrylonitrile	PAN	1.19 ^b	3
polyurethane	PU	1.05	3
polycarbonate	PC	1.2	3
ethylne vinyl acetate	EVA	0.92-0.95	3
polyvinylidene fluoride	PVDF	1.76-1.78	2
alkyd resin	ALK	1.42-2.20	2
poly (vinyl alcohol)	PVAL	1.2-1.3	2
polycaprolactone	PCL	-	2
phenolic resin	PF	1.25-1.30	1
polyvinyl methyl ether	PVME	-	1
polyterpene resins	PTR	-	1
polylactide	PLA	1.25	1
polystyrene acrylonitrile	SAN	1.08	1
poly (butyl methacrylate)	PBMA	1.07	1
poly (acrylate: styrene)	PAS	-	1
polyoxymethylene	POM	1.41-1.42	1
epoxy resin	EP	1.9	1
polyvinyl acetate	PVAc	1.19	1
polybutadiene acrylonitrile	PBAN	-	1
polydimethylsiloxane	PDMS	0.98	1
polyacrylamide	PAM	-	1
polyepichlorohydrin	-	-	1
polytetrafluoroethylene	PTFE	2.13-2.33	1
phenoxy resin	Phe	-	1
thermoplastic rubber	-	-	1
Styrene butadiene	SB	1.03-1.04	1
ethylene-propylene-diene rubber	EPDM	-	1
nitrile rubber	NBR	-	1
polysulfone	PSU	1.24-1.25	1
copolymer ^c	CM	-	4

729 a: Osswald, T. A., 2006. International Plastics Handbook: The Resource for Plastics Engineers. Hanser Gardner
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731 b: Morton, W. E, Hearle, J. W. S. 2008. Physical Properties of Textile Fibres (fourth edition). Woodhead Publishing

732 Limited, Cambridge.
733 c: copolymer or blends was only reported in the Arctic Central Basin (Kanhai et al., 2018), the Bohai Sea (Dai et al.,
734 2018), South China Sea (Ding et al., 2019) and River Thames (Rowley et al., 2020)

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