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Filella, M

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Filella and Turner
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POLICY BRIEF

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Towards the global plastic treaty: a clue to the complexity of plastics in practice

Montserrat Filella[1*] and Andrew Turner[2]

Abstract

Following the decision of the United Nations Environment Assembly (UNEA) to start negotiations for a legally binding treaty to end plastic pollution, discussions and reflections are ongoing on why and how plastic chemicals and polymers of concern should be integrated into the global plastics treaty. One of the points that has been identified as requiring attention is the reduction of the complexity of the composition of plastic objects. This article, addressed to decision-makers and other stake-holders involved in the negotiations, illustrates in a practical and graphical way what complexity means in the case of the presence of inorganic additives.

Keywords Inorganic additives, Plastic consumer products, Beached plastic litter

Driven by growing public and scientific concern, it was agreed at the United Nations Environment Assembly meeting in March 2022 (UNEA 5.2) to establish a global, legally binding treaty on plastics by 2024. The treaty aims to tackle the problem of plastic pollution by addressing the entire life cycle of plastics, from the extraction of raw materials to the disposal of manufactured products.

In this context, the fact that plastics are highly complex and often poorly characterised materials becomes extremely important and potentially problematic [1]. The main component is an organic, polymeric matrix, but plastics may also contain a wide range of chemicals. Specifically, it has been reported that more than 13,000 chemicals are associated with plastics and plastic production across a wide range of sectors and applications, of which over 3200 are monomers, additives, processing aids and non-intentionally added substances (UNEP, [15]). To this end, the scientific and regulatory communities face a number of concerns: first, the lack of access to basic, but crucial information on the identity, quantity and hazards of the chemicals used or present in different plastic products; second, impediments to recycling due to the presence and complexity of these chemicals; third, the over-consumption of our planet's limited resources [16]. Clearly, greater transparency throughout the plastics value chain is called for, requiring manufacturers to disclose the identity and quantity of all chemicals used and present in plastic products, as well as product use patterns and chemical release.

As a direct consequence of the lack of information on the composition of plastics, we have determined the presence and concentrations of inorganic chemicals in thousands of samples, ranging from consumer products to plastic litter collected from marine and lake beaches, over the past decade (e.g., [5, 6, 12–14]). Inorganic additives, contaminants and residues have received far less attention than organic chemicals and this is highlighted in a recent UNEP technical report on chemicals in plastics (UNEP, [15]) in which inorganics are omitted from the list of abbreviations and acronyms and are discussed in less than one out of more than ninety pages of text!

Although our research has focussed largely on potentially hazardous chemical elements and their possible impacts on human health and the environment, the

*Correspondence:
Montserrat Filella
montserrat.filella@unige.ch
[1] Department F.-A. Forel, University of Geneva, Boulevard Carl-Vogt 66, CH-1205 Geneva, Switzerland
[2] School of Geography, Earth and Environmental Sciences, Plymouth University, Drake Circus, Plymouth PL4 8AA, UK

results we have accrued also afford a valuable insight into and evaluation of the complexity of common plastics. Accordingly, and in the absence of global figures from manufacturers, the current text aims to provide practical examples for politicians, policy makers and delegates in UN treaty discussions. Specifically, we illustrate the complexity of various consumer plastic products and items of plastic litter collected from lake beaches that have been analysed using a simple and commonly employed, non-destructive technique (field portable energy-dispersive X-ray fluorescence (XRF) spectrometry). The instrument we use (Niton XL3t GOLDD+) has been both calibrated and performance-checked for various elements (including As, Ba, Bi, Br, Cd, Cl, Cr, Cu, Fe, Hg, Ni, Sb, Se, Sn, Pb, Ti, Zn) in plastics [14]. Limits of detection (LOD) vary according to sample composition and thickness and measurement time but indicative values from the manufacturer for plastics of unspecified thickness counted for 30 s range from about 3 mg kg^{-1} for As, Br and Se in polyethylene to > 100 mg kg^{-1} for Ba in polyethylene and Fe in polyvinyl chloride. Note, therefore, that when an element is not detected in a sample, it does not necessarily mean that it is not present; rather, it suggests that it is unlikely to exist in quantities sufficient to be an additive. An exception, however, could be barium, an element that is commonly present in plastics as the filler, $BaSO_4$, but whose detection by XRF is unfavourable because of its relatively high fluorescence X-ray energies. Absolute concentrations of elements detected in all samples referred to in this article can be found at https://doi.org/10.5281/zenodo.8305228. Note that where an element is not detected, its LOD value is shown to the right; where an element is detected, its detection limit can be determined from the counting error multiplied by 1.5. Note also that elements such as Ca and S are often present in plastics as additives but the XRF spectrometer is not calibrated for them in the plastics mode.

The presence of antimony as a reaction residue in polyethylene terephthalate (PET) bottles has been the subject of scientific scrutiny for more than 15 years due to the possible release of the potentially toxic metalloid into the contained liquid (mainly mineral water but often carbonated drinks) that is consumed [4]. Very little attention, however, has been paid to the presence of other chemical elements in PET bottles or their polyethylene caps. Table 1 shows the number of elements detected in nineteen PET bottles and in seventeen polyethylene caps sourced from Europe but whose brand names are not disclosed; absolute concentrations are provided at https://doi.org/10.5281/zenodo.8305228. The bottles contain up to five detectable chemical elements, with the expected constant presence of Sb but the frequent occurrence of Ba, Cl, Cr and Ti and isolated detection of Br, Cu and Ni. The caps contain up to six elements, with Sb never detected, and as above, Ba, Cl, Cr and Ti are often present. The precise origin or function (if any) of these elements is unknown, but the data serve to highlight how complex and heterogeneous the composition of common consumer plastic products can be.

Table 2 illustrates a selection of 50 plastic consumer products of varying polymeric constructions, purchased in Switzerland in 2018 by an independent stakeholder, where five or more chemical elements were detected (and including, for comparison, a product in which no elements were detected). The complete set of samples and their full quantitative compositions are shown at https://doi.org/10.5281/zenodo.8305228. Thirteen different elements were detected among the samples, and only two samples (#s 2 and 36) contained precisely the same elements (but not in the same order of concentration). Note that two items (#s 11 and 12) contained the toxic metal, Pb, at concentrations exceeding regulatory limits specified by the Restriction of Hazardous Substances Directive (European Parliament and Council, [2]). In theory, and as well as introducing further complexity to the plastic, this imposes constraints on material recycling, although in practice, it is doubtful that the presence of high quantities of Pb is even considered.

Figure 1 shows the composition of the different plastic parts of three Barbie dolls dated from 2012. These dolls are iconic, cultural objects, and serve as good examples of the complexity of the material supply chain. According to Sperber [11], "by the mid 1990s the nylon used in Barbie's hair came from Japan, the plastics for her body came from China, and her pigments from the US. Everything was assembled in China using US-made moulds and Japanese machines before being shipped and sold around the world". Our analyses reveal that the hair and many other components are constructed of polyvinyl chloride (from the high levels of Cl that the XRF spectrometer returned) but that one or more of eight other elements are present to differing degrees in the clothing and body parts. These differences are also evident in the same body parts of different dolls, and the different body parts of the same doll. Barbie dolls are a perfect representation of the use of plastics in the twentieth and twenty-first centuries, with a continuous change in their polymeric construction [10] and, as our results show, highly complex and variable elemental signatures.

It is not possible to determine the elemental composition of all types of plastics in all applications and sectors without an inordinate amount of work and resources. However, a useful composite picture of contemporary and historical plastics can be gained by considering litter collected from beach cleans as here material is derived from land-based and water-based sources that reflect a

Table 1 Number of elements detected by XRF spectrometry (shown in green) in nineteen PET bottles and seventeen polyethylene caps

Object	Ba	Br	Cl	Cr	Cu	Fe	Ni	Sb	Sn	Ti	Zn	Total
Bottles	✓		✓	✓				✓		✓		5
	✓		✓	✓				✓		✓		5
	✓		✓	✓				✓		✓		5
	✓		✓	✓	✓			✓				5
	✓		✓					✓				3
	✓		✓	✓				✓				4
	✓		✓	✓				✓		✓		5
								✓				1
	✓		✓	✓			✓	✓				5
	✓		✓	✓				✓		✓		5
	✓		✓	✓				✓				4
			✓	✓	✓			✓				4
			✓	✓				✓		✓		4
			✓	✓				✓		✓		4
			✓	✓				✓		✓		4
	✓		✓	✓				✓		✓		5
			✓	✓				✓		✓		4
	✓		✓					✓		✓		4
	✓	✓						✓		✓		4
Caps						✓	✓			✓	✓	4
	✓		✓	✓	✓					✓		5
	✓		✓	✓								3
	✓		✓	✓						✓		3
			✓	✓		✓				✓	✓	5
	✓		✓		✓		✓			✓		5
	✓									✓		2
			✓			✓	✓			✓		4
	✓		✓	✓	✓	✓				✓		6
			✓				✓			✓		3
	✓		✓	✓	✓					✓		5
	✓		✓	✓						✓		5
	✓		✓	✓						✓		4
	✓		✓			✓			✓			4
	✓		✓	✓						✓		4
	✓		✓	✓	✓					✓		5
			✓			✓			✓	✓	✓	5

The last column gives the total number of elements detected. Concentrations determined are given in https://doi.org/10.5281/zenodo.8305228.

multitude of sectors (domestic, commercial, industrial, tourism, fishing, agriculture, medical; [9]). Figure 2 illustrates plastic litter retrieved from a beach (Botanique) on Lake Geneva, Switzerland, in October 2018. On this occasion, all visible plastic items and fragments on the beach ($n = 89$) were collected and subsequently analysed by XRF spectrometry, with the distinctly different components of some samples analysed individually and the results shown in Table 3. In only one sample, none of the elements analysed were detected, and in one case, just one element was detected. Eight or nine elements were detected in three and two cases each, respectively, and seven elements were detected in twelve samples. Among the elements, Ba, Cl, Fe and Ti were most frequently detected, while Br, Cd, Cr, Cu, Ni, Pb and Zn were detected in at least ten cases each. Elements not detected in the bottles and consumer samples shown in Table 1 were also found in among the beached samples (As, Bi and Se). Aside from fragments from the same object and grouped samples of similar construction (e.g., #s 46–57), identical elemental signatures were observed in six pairs of samples. However, in these cases concentrations of one or more element differed considerably (see https://doi.org/10.5281/zenodo.8305228).

According to Wiesinger et al. [17], a wide range of chemicals in plastics can serve the same function, and the same chemical can sometimes serve multiple functions. Moreover, it is not clear whether all chemicals in plastics are functional or necessary, and to what extent plastics are contaminated, by intentional or unintentional additions during manufacture or recycling. These factors, coupled with a general lack of coordination regarding material sourcing, processing and quality control between manufacturers, has resulted in plastics with the same polymeric matrix and application often having highly variable chemical compositions (and as

Table 2 Chemical elements detected by XRF spectrometry in 50 consumer products bought in Switzerland in 2018

Eight elements


#11
Ba, Br, Cd, Cl, Cr, Pb, Sb, Ti


#12
Ba, Cl, Cr, Pb, Sb, Sn, Ti, Zn


#20
Ba, Br, Cl, Cr, Pb, Sb, Ti, Zn

Seven elements


#6
Br, Cl, Cr, Fe, Sb, Ti, Zn

Six elements


#2
Ba, Cl, Cu, Fe, Ti, Zn


#25
Ba, Br, Cl, Sn, Ti, Zn


#23
Ba, Cl, Fe, Pb, Ti, Zn


#30
Cl, Fe, Pb, Sb, Ti, Zn


#33
Ba, Cl, Cr, Cu, Sn, Ti


#36
dark blue
Ba, Cl, Cu, Fe, Ti, Zn

Five elements


#45
(yellow stripe)
Ba, Ni, Sb, Ti, Zn


#3
Ba, Cu, Fe, Ni, Ti


#21
Ba, Cl, Cu, Ti, Zn


#29
Ba, Cl, Sb, Ti, Zn


#31
Cr, Cu, Fe, Ti, Zn

None


#15

Objects are classified in descending order of number of elements and only where more than five elements were detected (the isolated sample with no detectable elements is also illustrated). Concentrations for all of the products can be found in https://doi.org/10.5281/zenodo.8305228

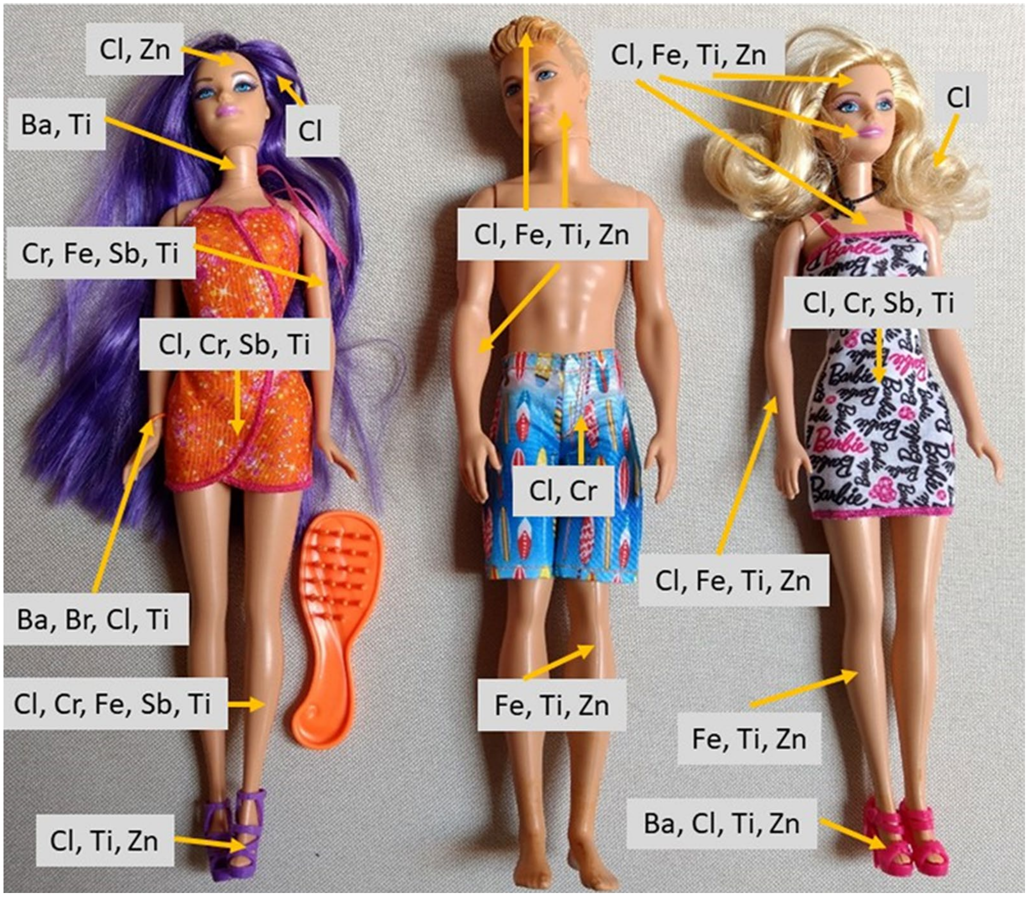

Fig. 1 Elements detected by XRF spectrometry in different components of three Barbie dolls manufactured in 2012. Concentrations determined are given in https://doi.org/10.5281/zenodo.8305228

Fig. 2 Plastic objects (*n* = 89) collected from Botanique Beach, Geneva, Switzerland (46°13′N, 6°08′E) on 18 October 2018

Table 3 Number of elements detected by XRF spectrometry (shown in green) in the 89 plastic objects and fragments illustrated in Fig. 2 that had been collected from Botanique Beach, Geneva, Switzerland (46°13′N, 6°08′E) on 18 October 2018

Object	As	Ba	Bi	Br	Cd	Cl	Cr	Cu	Fe	Ti	Ni	Pb	Sb	Se	Sn	Zn	Total
1		✓				✓	✓	✓	✓	✓	✓						7
2		✓				✓	✓	✓	✓	✓							6
3		✓				✓	✓	✓	✓	✓	✓						7
4		✓				✓			✓	✓	✓	✓					6
5		✓							✓	✓	✓						4
6		✓				✓			✓	✓					✓		5
7		✓	✓			✓	✓		✓	✓						✓	7
8		✓			✓	✓				✓						✓	5
9				✓		✓			✓	✓						✓	5
10		✓				✓	✓		✓	✓		✓				✓	7
11		✓				✓	✓		✓	✓		✓	✓				7
12		✓						✓	✓	✓							4
13		✓						✓		✓							3
14						✓			✓	✓						✓	4
15		✓				✓	✓		✓	✓							5
16						✓			✓	✓	✓						4
17		✓					✓	✓	✓	✓	✓						6
18		✓				✓			✓							✓	4
19		✓				✓			✓	✓					✓		5
20		✓				✓	✓		✓	✓	✓					✓	7
21		✓							✓	✓							3
22		✓				✓			✓	✓	✓						5
23																	0
24		✓				✓		✓	✓	✓							5
25a		✓								✓							2
25b		✓			✓	✓			✓	✓							5
26						✓											1
27		✓						✓	✓	✓							4
28						✓			✓	✓	✓					✓	5
29		✓		✓	✓	✓			✓	✓		✓				✓	8
30		✓		✓		✓	✓	✓	✓	✓			✓			✓	9
31		✓		✓		✓			✓	✓		✓					6
32		✓				✓	✓	✓	✓								5
33		✓				✓			✓	✓						✓	5
34		✓		✓				✓	✓	✓							5
35					✓				✓	✓						✓	4
36a						✓			✓	✓							3
36b		✓				✓		✓	✓	✓							5
37a		✓								✓							2
37b		✓				✓											2
38										✓	✓						2
39				✓		✓	✓		✓	✓		✓				✓	7
40				✓		✓	✓		✓	✓						✓	6
41		✓				✓	✓		✓	✓						✓	6
42		✓		✓		✓	✓		✓	✓						✓	7
43		✓		✓		✓	✓		✓	✓						✓	7
44		✓								✓							2
45								✓	✓	✓						✓	4
46						✓	✓	✓	✓	✓						✓	6
47		✓						✓	✓	✓						✓	5
48						✓			✓	✓						✓	4
49-52									✓	✓							2
53-57									✓	✓						✓	3
58				✓		✓		✓	✓	✓						✓	6
59						✓	✓	✓	✓	✓							5
60						✓			✓	✓							3
61		✓							✓			✓					3
62		✓			✓	✓	✓		✓	✓				✓		✓	8
63	✓	✓			✓			✓	✓	✓				✓		✓	8
64		✓				✓	✓	✓	✓	✓			✓				7
65		✓			✓	✓			✓	✓	✓					✓	7
66		✓				✓	✓			✓							4
67		✓				✓		✓	✓	✓						✓	6
68							✓	✓	✓	✓							4
69		✓			✓	✓			✓	✓		✓					6
70		✓			✓		✓		✓	✓		✓				✓	7
71		✓				✓			✓	✓						✓	5
72		✓				✓	✓		✓	✓							5
73						✓	✓		✓	✓							4
74		✓				✓	✓		✓	✓						✓	6
75				✓		✓			✓	✓						✓	5
76									✓	✓		✓				✓	4
77				✓								✓					2
78						✓	✓		✓	✓							4
79-80					✓	✓	✓	✓	✓	✓							6
81		✓				✓	✓	✓	✓	✓		✓			✓	✓	9
82		✓				✓	✓	✓	✓	✓							6
83		✓				✓		✓	✓	✓							5
84-87		✓				✓		✓	✓	✓							5
88		✓				✓		✓	✓	✓							5
89		✓				✓			✓	✓					✓	✓	6

Note that the 92 analyses include multiple components of three objects. The last column gives the total number of elements detected. Concentrations determined are given in https://doi.org/10.5281/zenodo.8305228 exemplified in Table 1). What is clear is that any attempt to achieve the goal of plastic circularity requires a much better understanding of chemical composition and, ideally, consistency or simplification during manufacture. Chemical simplification and disclosure of composition more generally are key requirements to counter the impacts of increasing chemical pollution [3, 7, 8]. Accordingly, and with regard to plastics, we trust that the way in which we have provided practical and easy-to-understand information for all stakeholders will contribute to progress in this direction.

Abbreviations

LOD Limit of detection
PET Polyethylene terephthalate
XRF X-ray fluorescence

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Author contributions
MF collected the samples and analysed them by XRF, drafted the first and last versions of the manuscript, including figures. AT provided the means of analysis, discussed the results and edited the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials
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Declarations

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Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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