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Julien Boucher and Guillaume Billard

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# THE CHALLENGES OF MEASURING PLASTIC POLLUTION

Guillaume Billard and Julien Boucher  
Environmental Action (EA)



Julien Boucher is founder and director of EA – Shaping Environmental Action, an innovation and eco-design centre based in Switzerland ([shaping-ea.com](http://shaping-ea.com)), as well as senior scientist at the University of Applied Sciences and Arts Western Switzerland (HES-SO, HEIG-VD).

Guillaume Billard recently graduated from Newcastle University (UK) with an MSc in International Marine Environmental Consultancy.

Since 2014, the EA team has been working towards better integration of plastic pollution in footprinting and Life Cycle Assessment methodologies, and hopes to contribute to “closing the plastic tap”.

## KEYWORDS

- PLASTIC FOOTPRINT
- MARINE POLLUTION
- LIFE CYCLE ASSESSMENT
- ECO-DESIGN

Plastic is a single word for a multifaceted reality, encompassing a wide variety of polymers and additives with different chemical and physical properties. The end products range from single-use plastic bags, food wraps and plastic bottles, to fishing lines, buoys, and synthetic fibres used in the clothing or fishing industries.

As the use of plastic is pervasive, so is plastic pollution. An estimated 10 million tonnes of plastic leaks into the ocean each year, causing an unprecedented environmental crisis. Measuring or forecasting this issue is a complex and challenging task, due to technical limitations and uncoordinated assessment campaigns. Acting to tackle this issue requires adequate metrics to guide and prioritise action at different levels, ranging from sound product design and efficient regional infrastructure, to adequate policies and enforcement.

## INTRODUCTION

It is not only our feet which leave a footprint on sandy beaches – our heavy reliance on plastic materials is creating a visible yet pervasive “plastic footprint” in the environment. This increasing usage is generating considerable amounts of litter, ultimately reaching the marine environment. Considered a major threat to both wildlife and human wellbeing, plastic pollution is now ubiquitous in the World ocean (UN Environment, 2018), causing an unprecedented environmental crisis, with an estimated 10 million tonnes of litter leaking into the marine environment every year (Boucher and Friot, 2017).

Subject, among other parameters, to currents and wave action, plastics are likely to accumulate in different compartments of the oceans (e.g. surface, sediments), and break down into submillimetre-sized debris which can ultimately be ingested by marine life.

This rise in plastic consumption is not surprising, as these materials provide many benefits to society through their malleability, durability and lightness, together with low production costs. For many applications, plastics can even offer lower carbon footprint alternatives compared to other materials (Boucher and Friot, 2017).

Since the 1950s, yearly production of plastics has risen from close to zero to above 335 million tonnes in 2017, with an annual increase forecast at 4% for the coming years (Geyer, Jambeck and Law, 2017; PlasticsEurope, 2017). This plastic crisis stresses the need to use better forecasting metrics to manage environmental trade-offs and to guide industries and governments towards sound product design and waste management infrastructure.

At present, current Life Cycle Assessment (LCA) and footprinting methods used to guide companies and designers still neglect plastic pollution.

This review firstly aims to give an overall description of the plastic pollution issue, with a focus on the quantities of plastic flowing into oceans (i.e. the “leakage”). Secondly, it

will further discuss current knowledge gaps and challenges underlying both plastic assessment at sea and forecasting plastic leakage (i.e. “footprinting”). Lastly, the conclusion will stress on the need to act now and, concomitantly, on both action and developing these metrics.

## CURRENT KNOWLEDGE STATUS ON PLASTIC POLLUTION

### HOW MUCH PLASTIC IS LEAKING?

Several studies have inventoried and quantified different sources of plastic leakage either at country level or globally (Lassen et al. 2015; Essel et al. 2015; Magnusson et al. 2016). We call leakage the quantity of plastic flowing into waterways and, ultimately, into the oceans. Global plastic leakage is estimated in the order of 10 million tonnes per year (Mt/y), with different authors presenting yearly values of:

- 4.8 Mt/y to 12.7 Mt/y (Jambeck et al. 2015)
- 8.28 Mt/y (UN Environment, 2018)
- 12.2 Mt/y (EUNOMIA, 2016)
- 10 Mt/y (Boucher and Friot, 2017).

Plastics can be encountered in two forms: large plastic wastes called macroplastics, which usually enter the marine environment in their manufactured sizes, and small plastic particulates below 5 mm in size called microplastics.

The latter break down into two types:

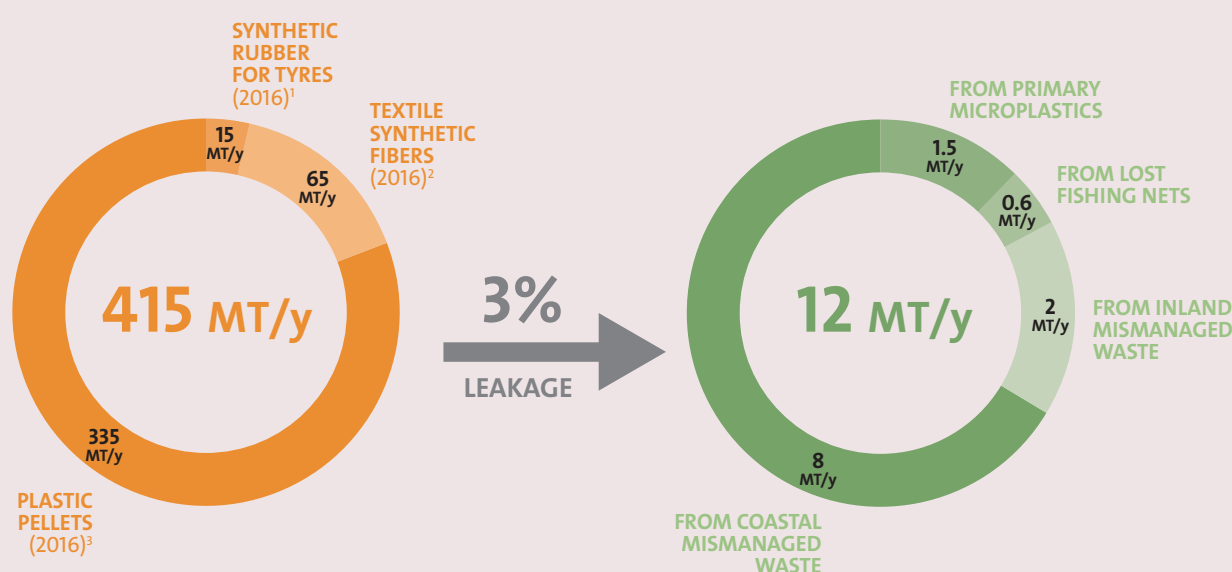
- **primary microplastics** are directly released into the environment in the form of small particles. They can be a voluntary addition to products such as scrubbing agents in toiletries and cosmetics (e.g. shower gels). They can also originate from the abrasion of large plastic objects during manufacturing, use or maintenance, such as the erosion of tyres when driving or the abrasion of synthetic textiles during washing;
- **secondary microplastics** originate from the degradation of larger plastic items into smaller plastic fragments once exposed to the marine environment. This happens through photodegradation and other weathering processes of mismanaged waste such as discarded plastic bags or from unintentional losses such as fishing nets.

### WHAT IS THE CONTRIBUTION OF THE DIFFERENT SOURCES?

This question remains a subject of debate. Figure 1 shows the main sources together with their most frequently cited quantities (green pie chart), in comparison to the global amounts of plastic produced (orange pie chart). This comparison sheds light on a relative leakage rate of 3%, meaning that 3% of all plastic put on the market will ultimately end up in the ocean.

A higher estimate has been put forward by the World Economic Forum, with an estimated 32% of single-use packaging escaping collection systems (WEF, 2016).

## Yearly plastic leakage into the marine environment based on worldwide plastic pollution data



1 <https://www.statista.com/statistics/271651/global-production-of-the-chemical-fiber-industry/> & [http://www.rubberstudy.com/documents/WebSiteData\\_Feb2018.pdf](http://www.rubberstudy.com/documents/WebSiteData_Feb2018.pdf)

2 <https://www.statista.com/statistics/271651/global-production-of-the-chemical-fiber-industry/>

3 [https://www.plasticseurope.org/application/files/5715/1717/4180/Plastics\\_the\\_facts\\_2017\\_FINAL\\_for\\_website\\_one\\_page.pdf](https://www.plasticseurope.org/application/files/5715/1717/4180/Plastics_the_facts_2017_FINAL_for_website_one_page.pdf)

Source: Boucher et al. in press; IUCN – The marine plastic footprint

Figure 1

The section below describes leakage from four main sources, estimating the quantities flowing into the marine environment as reported in the literature:

**i. Coastal Mismanaged Plastic Waste (MPW): 8 Mt/y**

The most commonly cited orders of magnitude were published by Jambeck et al. in 2015. This research focused on the amount of mismanaged plastic waste likely to be generated by the coastal population of 192 countries living in a 50 km fringe from the shore. Calculations were based on the mass of waste generated per capita annually, the percentage of plastic materials in the waste and the percentage of mismanaged plastic waste likely to enter the oceans as debris (which includes the share of inadequately managed waste per country and a default global littering rate of 2%).

This research concluded that annual leakages of MPW into the marine environment range from 4.8 to 12.7 Mt/y. Additionally, other MPW estimations have been published, varying from 3.87 Mt/y (UN Environment, 2018) to 9 Mt/y (EUNOMIA, 2016) on their global plastic leakage estimate of 8.28 Mt/y and 12.2 Mt/y respectively.

**ii. Inland MPW: 2 Mt/y**

Contributions of rivers to global the leakage fluctuate depending on seasonality and geographical location. Globally, rivers would be responsible for plastic waste inputs ranging from 1.15 Mt/y to 2.41 Mt/y, with 67% of these emissions originating from Asia alone (Lebreton et al. 2017).

Interestingly, the above-mentioned study is supported by field measurements showing good correlation between population densities, waste management data and results from observational river studies.

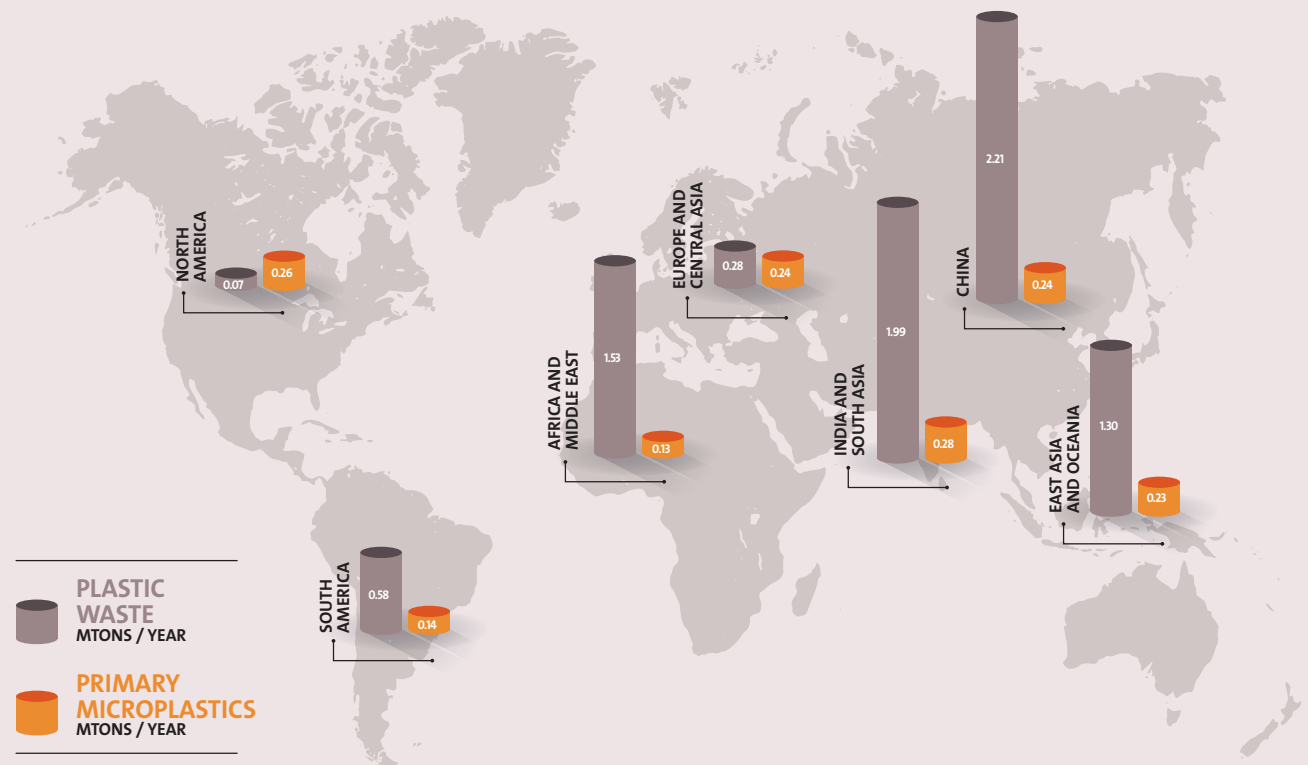
In addition, another study estimated riverine inputs as ranging between 0.41 Mt/y and 4 Mt/y (Schmidt, Krauth and Wagner, 2017). Discrepancies between the two studies are due to different parameters used, such as the number of coastal countries considered.

**iii. Lost fishing gear: 0.6 Mt/y**

The fishing and aquaculture sectors emit large quantities of litter (e.g. derelict gear), including 0.6 Mt of microplastics per year for the fishing industry (Boucher and Friot, 2017). For example, field studies report a prevalence of blue fibres (nylon) specific to fishing devices. Other orders of magnitude have been published, with, for example, a loss

## Global releases of primary microplastics and plastic waste into the World ocean

Comparison with plastics originating from mismanaged wastes



Source: Boucher, J. and Friot D. 2017

Figure 2

rate of derelict fishing gear of 1.15 Mt/y (EUNOMIA, 2016). The sources here are very scarce and the precise contribution is highly unreliable. In addition, shipping litter thrown overboard, which is supposedly prohibited, also contributes to overall plastic pollution with estimates of 600 kt/y (EUNOMIA, 2016).

#### iv. Primary microplastics: 1.5 Mt/y

In this study, we consider that 1.5 Mt/y enters the marine environment in the form of primary microplastics. However, many sources differ on the contribution of primary microplastics to the overall plastic loss. Primary microplastics are estimated at:

- 3.01 Mt on a total plastic loss of 8.28 Mt/y (UN Environment, 2018)
- 1.5 Mt/y on a total plastic loss of 8 Mt/y (Boucher et Friot, 2017)
- 0.95 Mt on a total plastic loss of 12.2 Mt/y (EUNOMIA, 2016).

In percentage share, it equates to approximately 36%, 15% and 8% of global plastic leakage (UN Environment, 2018; Boucher and Friot, 2017; EUNOMIA, 2016). Per sources, leakages due to tyre abrasion would equate to 1,400 / 420 / 270 kt/y (UN Environment, 2018; Boucher and Friot, 2017; EUNOMIA, 2016). Road marking leakages: 590 / 105 / 80 kt/y and washed out microfibres estimated at 260 / 525 / 190 kt/y according to the same sources.

Although these estimates are still a subject of debate, there is a consensus on the fact that they are mainly caused by the leakage, dependent on regional conditions and archetypes.

Leakage of macroplastics from mismanaged waste is dominant in coastal countries, especially those with less adapted waste management facilities (Boucher and Friot, 2017). Figure 2 below the contribution of primary microplastics and mismanaged waste to global plastic pollution.

These regional differences are the result of varied patterns and pathways that depend on local characteristics, such as population densities, GDP, cultural habits and the effectiveness of local infrastructure to retain waste, which concurs with the IPAT theory (Impact = population \* affluence \* technology) (Ehrlich and Holdren, 1971).

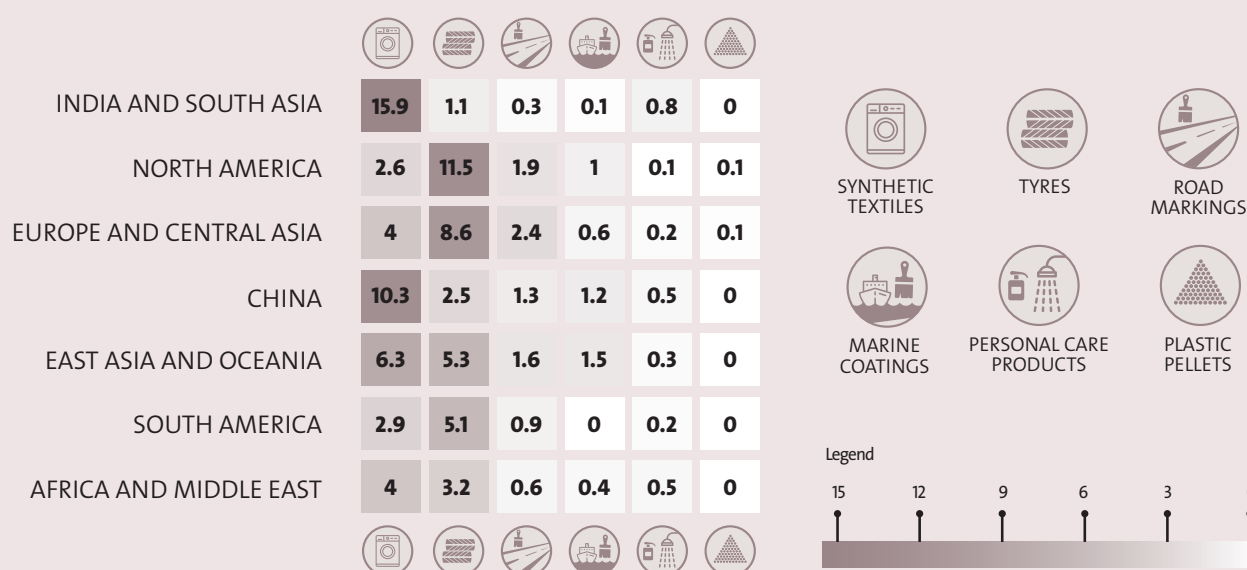
These regional and sectoral differences are further illustrated in Figure 3 for different microplastic sources. Shaping actions requires defining emissions hotspots, which urgently needs the development of an industry-specific and regionalised plastic footprint methodology.

Such footprinting approaches could be based on measuring quantities as well as integrating the assessment of the resulting environmental and human health impacts:

- Macro-sized debris:* affects both wildlife and human wellbeing. Large items can be ingested by marine megafauna (de Stephanis et al. 2013), which can ultimately lead to death by starvation. Entanglement in derelict fishing gear ("ghost fishing") is also a growing concern. Plastic pollution economically affects human coastal communities, with approximately €18 million per year being spent on beach litter removal in the UK alone (Lee, 2015.)

## Global releases (%) to the World oceans by geographical area and sources

Key sources among regions (total amount to 100%)



Source: Boucher, J. and Friot D. 2017

Figure 3



- ii. *Meso/micro-sized debris*: plastic debris have also been found encrusted with organisms such as bryozoans (moss animals) or algae, creating a transport vector for invasive species (Gregory, 2009). This transport is a considerable threat to areas where endemism is important, such as isolated sub-Antarctic islands. Additionally, ecosystem impacts are suspected through the accumulation of microplastics in the food chain, which could potentially transfer to humans via direct consumption of seafood. It is estimated a 50-fold increase in surface microplastic concentrations by 2100 (from 0.2-0.9 particles m<sup>3</sup> in 2010 to 9.6-48.8 particles m<sup>3</sup> predicted in 2100) (Everaert et al. 2018). However, no direct effects linked to free-floating microplastics are expected (excluding some toxical pollutants adsorbed at the surface of these particles –e.g. some pesticides) in normal conditions, though areas with higher concentrations than average could potentially be at risk (Everaert et al. 2018). A precise estimation of these potential and different impacts of plastic debris will still require further years of research.

A comprehensive assessment of these impacts within a life-cycle based framework would make it possible to (i) compare the impact of different plastic leakages (e.g. different polymers or different object shapes), and (ii) allow for analysis of trade-offs between plastic-related impacts and other potentially severe environmental burdens.

Although the theoretical framework and impact pathways seem quite clear, supporting data (i.e. the fate factors, characterisation factors and ecotoxicological data) are not available yet. As a result of this knowledge gap, a plastic leakage inventory indicator should be used to guide decision-making in the short term (FSLCI, 2018).

This first section has described the current knowledge status of plastic pollution in the marine environment, with the overarching aim of describing the main issues and findings. The following sections will provide an overview of the challenges surrounding the use of models for plastic leakage forecasting as well as the challenges for measuring plastic at sea.

## THE CHALLENGES OF FORECASTING PLASTIC POLLUTION

Forecasting plastic pollution is a challenging endeavour. As seen above, at a global level, many uncertainties prevail, which explains the discrepancies in numbers. These uncertainties can either be structural (related to the understanding of the mechanisms and pathways of the leakage) or data related (related to the availability of reliable datasets, which are particularly difficult to obtain in certain countries).

Developing a more specific and actionable methodology requires overcoming some of these uncertainties. Listed in the sections below are the main challenges that have to be solved in order to yield a reliable forecasting footprint method.

An attempt of a plastic footprinting framework methodology is described in Figure 4, highlighting the different loss patterns and release pathways.

## MODELLING THE LEAKAGE FROM MISMANAGED WASTE AND FROM LITTERING

Mismanaged waste is commonly defined as plastic waste managed in a way that might include some leakage into the marine environment. This includes waste entering non-sanitary landfills, dumpsites, or tipped/littered.

Current limitations of this approach can be stressed, such as:

- i. Lack of a standardised formula or dataset to calculate mismanaged waste, thus different approaches yield different results.
- ii. Littering estimations are by nature complex to produce; litter may be identified from municipality cleaning operators' statistics, but not for the fraction that "falls through the cracks" (i.e. the leakage). This fraction is by definition not measured, and very difficult to "guesstimate". A proxy of littering has been brought forward by Jambeck et al. (2015), applying 2% for all countries.
- iii. Release rates from mismanaged waste are rarely based on evidence, thus mainly hypothetical. The release pathways are poorly understood and release rates therefore provide indications rather than estimations. These release rates are typically described as varying from 10% to 40% (Jambeck et al. 2015; UN Environment 2018) without presenting regional variations. Factors such as cultural behaviours (e.g. littering habits), climatic conditions (e.g. effect of rain or wind on dispersal of waste from dumpsites) and geographic specificities (e.g. distance to shore and waterways) are expected to have a significant influence.

These strong uncertainties in the model should not prevent stakeholders from adopting priority actions. Using circularity indicators may be a reasonable option in the short term, while awaiting the definition of models to refine leakage pathways.

## MICROPLASTIC SOURCES AND PATHWAYS

The leakage of primary microplastics is measured as a function of a loss rate and a release rate. The loss rate measures the quantity of plastics lost from a specific activity (e.g. driving, household washing). The release rate measures the fraction of this loss that ultimately reaches the ocean, i.e. is not captured in waste treatment plants or other infrastructure.

Loss rate estimates are now available in the literature, allowing for generic plastic footprint calculations. However, the drivers that make these rates fluctuate from low to high bonds remain unclear and hinder the use of such metrics for eco-design guidance.

The release rate is still bound to large uncertainties, as a result of the high complexity of the release pathways

# Plastic footprint framework

The diagram illustrates the Plastic footprint framework, which is structured around two main dimensions: **CIRCULARITY** and **MATERIALITY**.

**Plastic Production and Conversion:** This stage includes **Plastic Production** and **Plastic Conversion**. It is associated with **PRIMARY MICROPLASTICS (UNINTENTIONAL)** (D) and includes icons for a pyramid, a washing machine, a pile of fabric, a road, and a ship, along with the text "+ others".

**Plastic Use:** This stage includes **Plastic Use** and is associated with **COSMETICS** (C) and **FISHING NETS** (B). It includes icons for a bottle and a fishing net.

**Plastic Waste:** This stage includes **Plastic Waste** and is associated with **SINGLE-USE PLASTICS** (A). It includes an icon for two bottles and the text "Mismanaged waste".

**Loss and Release:** The **LOSS** is represented by a green chevron shape. The **RELEASE 1** is represented by an orange chevron shape. The **RELEASE 2 (the leakage)** is represented by a red chevron shape. The **100 %** label is present under the **Plastic Use** and **Plastic Waste** stages.

**Beach Clean-Up:** This stage involves the **Quantification & clasification of flows** (note the typo) leading to an **INVENTORY**.

**Fate (biodegradability):** This stage leads to the **PLASTIC FOOTPRINT**.

**Full Fate:** This stage leads to **Exposure**, which leads to **Effect**, which leads to **IMPACTS (LCA)**.

Source: Boucher et al. in press; IUCN – The marine plastic footprint

Figure 4

## THE FATE AND IMPACTS QUESTION

## THE CHALLENGES OF MEASURING PLASTIC POLLUTION IN THE FIELD

This quantity is almost two orders of magnitude below the predictions of annual inputs based on modelled results (4-12 Mt, Jambeck et al. 2015). There is a debate in the scientific community regarding the spatial distribution and fate of plastics in the water column. It appears unclear as to whether plastics sink and hence accumulate in the deep-sea (thus not measured by surface sampling, Woodall et al. 2014; Koelmans et al. 2017) and/or may be accumulated in the food web or oscillating in the water column (Kooi et al. 2017).

Another hypothesis to bear in mind is that contemporary sampling methods are possibly not suitable for the detection of very small particles and correction models are rarely implemented.

- i. Some studies focusing on surface quantification do not apply correction models when sampling in windy conditions. Concentrations can be largely underestimated due to wind and wave events. This is a major drawback in plastic pollution assessments as it has been shown that plastic (mainly micro-mesoplastic) concentrations could be 2.5 times higher when wind correction models are applied in > 8 knots conditions (Kukulka et al. 2012).
- ii. When sampling surface debris, there is a tendency in the literature to provide metric results in average particles by surface area (items km<sup>-2</sup>) and total particles counted. The weight of debris is rarely provided as additional information.
- iii. Sampling methodologies (towing time and speed, net dimensions and mesh sizes) significantly fluctuate between studies, influencing the catchability of plastics. There is a lack of a standardised approach for sampling plastic at sea, and due to an inconsistent reporting scheme, datasets are rarely comparable (Whitacre, 2012).
- iv. Microplastic abundance seems to differ with depth in the water column. This mainly concerns very small debris (10 µm or 0.01 mm) that present different sinking rates compared to larger microplastics (Enders et al. 2015). It appears that the abundance of larger debris (e.g. 1 mm) decreases with depth, and therefore concentrates mainly in the surface layer. Smaller debris (10 µm) show a relatively constant and high abundance from 0 to 100 m depth. Additionally, another study discovered that the abundance of < 300 µm debris increased with depth, with artificial fibres accounting for the main plastic type in the water column (Dai et al. 2018).
- v. There are uncertainties regarding settling rates of microplastics from the surface to the seafloor with two main factors influencing this process: biofouling and water stratification.  
*Biofouling*: is defined as “the accumulation of organisms on submerged surfaces affecting the hydrophobicity and buoyancy of plastic” (Kooi et al. 2017). Once loaded with organic matter, particles start to oscillate in the water column in different ways, depending on the photosynthesis rate (Kooi et al. 2017).

*There is a debate in the scientific community regarding the spatial distribution and fate of plastics in the water column. It appears unclear as to whether plastics sink and hence accumulate in the deep-sea and/or may be accumulated in the food web or oscillating in the water column.*

*Water stratification and circulation*: water bodies of different densities occur in some oceans and seas such as the Mediterranean. For example, surface and deep-water masses display independent circulation patterns but up to now, the influence of this circulation on plastic transfer toward the deep sea has not been documented (El-Geziry and Bryden, 2010).

Analysing plastic samples relies upon very manual procedures, ultimately slowing down the processes and thus

reducing the extent of sampling areas. Developing more automated measurement protocols, for example based on machine learning, would enable considerable progress in this field. Also, tracing specific particles such as tyre dust would be required to validate orders of magnitude provided by top-down modelling.

## CONCLUSION

There is no simple solution to this complex and global issue. Policy makers and industries are currently taking decisions in a situation of high uncertainties. We should not forget that in some cases, plastic materials provide far more environmental benefits than drawbacks, for example when lighter material leads to reduced CO<sub>2</sub> emissions during transport.

We can manage only what we can measure. Efficient metrics accounting for plastic pollution are needed in order to guide sound eco-design and waste management strategies, while accounting for complex environmental impact trade-offs.

Despite all the urgency of action and the need for efficient metrics, it should not be forgotten that common-sense solutions rely on the avoidance of littering or plastic over-usage, and such solutions need to be activated immediately. In addition, sound waste management strategies would be beneficial in areas where they are lacking, in addition to public awareness. These are small-scale actions, yet achievable and would contribute to erasing our plastic footprint from the marine environment.



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