

Plastics in the Marine Environment

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About Eunomia

Eunomia is one of the leading research organisations focusing on the sources and impacts of waste in the marine environment. We have undertaken a range of studies in this area, investigating the sources, pathways and impacts of marine litter, and exploring the effectiveness of preventative and removal measures.

Clients in this field include the UN, European Commission and the Clean Europe Network. Our work has given us a detailed knowledge of the relative strengths of different monitoring approaches, a solid understanding of the extant literature (and areas where research is lacking), and excellent contacts with academics and practitioners across the globe.

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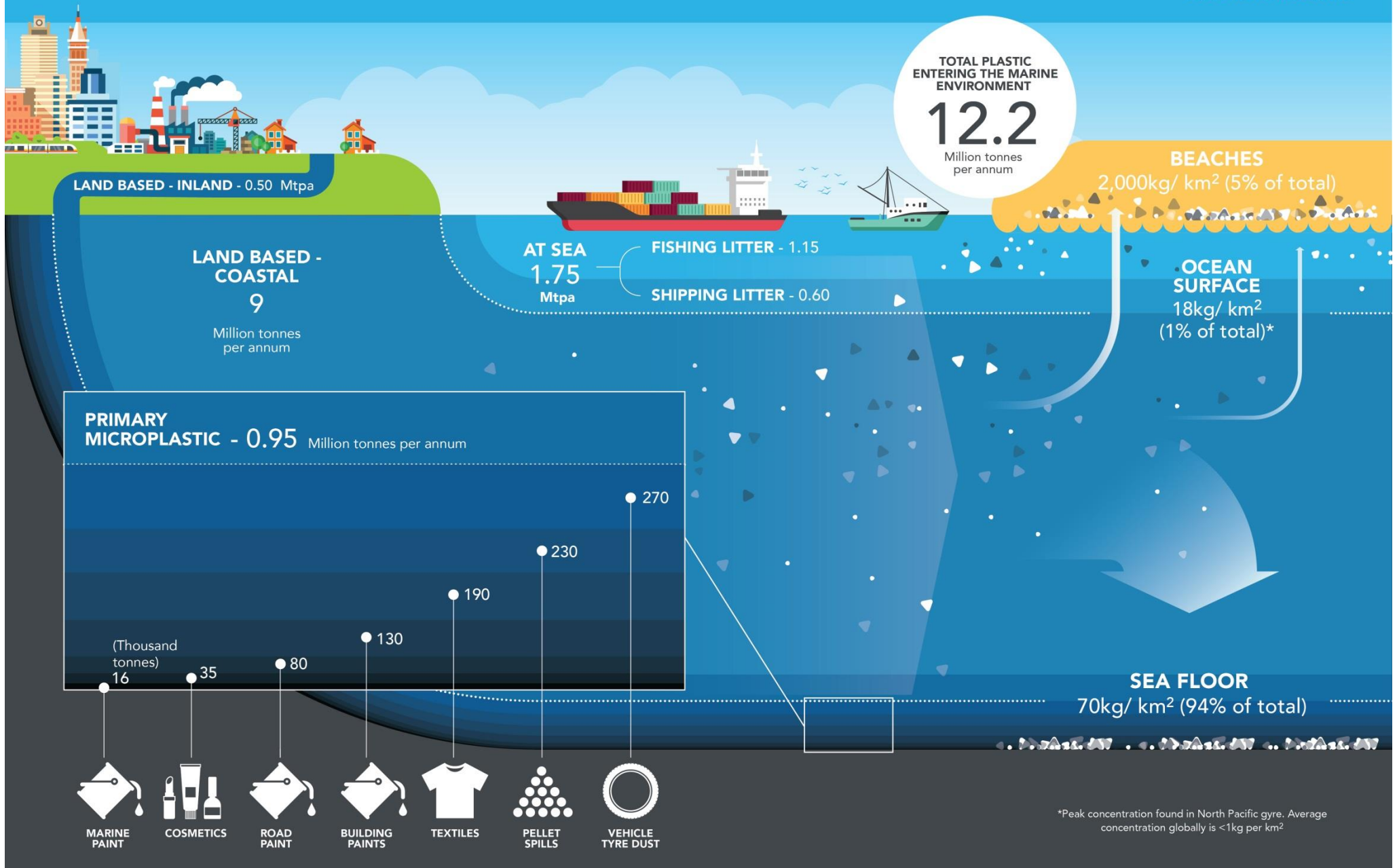
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PLASTICS IN THE MARINE ENVIRONMENT: WHERE DO THEY COME FROM? WHERE DO THEY GO?

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1.0 Introduction

Knowledge of the sources and fate of plastics in the marine environment is far from complete, but what is known is deeply troubling. Increasing awareness of the problems associated with marine plastics is beginning to translate into calls for action, but without good information, it is difficult for policy makers and other concerned parties to know where to target efforts in order to yield the greatest impact.

The infographic shown at the start of this report presents an indicative snapshot based on what we believe to be the best data currently available to highlight the principal sources of plastic in our oceans, and where this material is deposited. It shows that:

- Over 80% of the annual input comes from land-based sources.
 - The main contributor is larger plastic litter, including everyday items such as drinks bottles and other types of plastic packaging.
 - Primary microplastic emissions also have an important role.
 - The remainder comes from plastics released at sea, the majority as a result of fishing activities – for example, due to lost and discarded fishing gear.
- 94% of the plastic that enters the ocean ends up on the sea floor. There is now on average an estimated 70kg of plastic in each square kilometre of sea bed.
- Barely 1% of marine plastics are found floating at or near the ocean surface, with an average global concentration of less than 1kg/km².
 - This concentration increases at certain mid-ocean locations, with the highest concentration recorded in the North Pacific Gyre at 18kg/km².
- By contrast, the amount estimated to be on beaches globally is five times greater, and importantly, the concentration is much higher, at 2,000kg/km².
 - While some may have been dropped directly, and other plastics may have been washed up, there is a 'flux' of litter between beaches and the sea. By removing beach litter, we are therefore cleaning the oceans.

These findings have implications for the focus of efforts to tackle the problem. Prevention is preferable to cure, and the greatest opportunity to prevent plastic entering the ocean is to take steps to reduce plastic litter on land. Carrier bag charges have already proved a cost-effective step in the right direction, and the same approach could be taken to other commonly littered plastic items, like take-away cups and disposable cutlery. Deposit refunds on beverage containers would help incentivise people to return them for recycling, and reduce the amount littered.

Removing plastic from the oceans will be difficult. Despite the high profile of projects intended to clean up plastics floating in mid-ocean, relatively little actually ends up there, and this approach appears to be of limited value. The most practical measure that can be deployed is to focus efforts on regular beach clean ups.

This report explains the sources of information underlying the infographic, and the basis upon which these statements have been made.

2.0 Data Sources

For clarity, the tonnage estimates presented in the infographic for different sources of marine plastics are mid-points of ranges. Section 2.1 presents these ranges, and the sources from which they are drawn. The ranges reflect the lack of certainty in the actual amounts entering the marine environment each year.

The left hand side of the diagram shows the annual *flows* of plastics into the marine environment. It is possible that there is some overlap between the land-based coastal and land-based inland (which is taken to be plastics that flow to the sea via rivers), as some of the mismanaged or littered plastic items within 50km of coastlines may reach the sea via rivers, a common means of transmission for inland plastic litter.

The right hand side looks at the *stock* of marine plastic, to which each year's annual flow keeps providing additional plastic. Clearly, one would expect the stock in the marine environment to keep increasing so long as the flows continue. The figures on the right showing the concentration of plastics in the different marine compartments (on beaches, on the ocean floor, and floating at or near the ocean surface) might also therefore be expected to increase over time. Accordingly, these figures should also be considered to be an indicative snapshot.

2.1 Where Do They Come From?

The sources consulted in reaching our estimates of the flows of plastic into the marine environment are:

- **Land-based coastal** – mid-point estimate of 9 million tonnes per annum (range 4.8 to 12.7 million tonnes per annum) from mismanaged waste within 50km of coastlines around the world. Source: Jambeck, J.R., Geyer, R., Wilcox, C., et al. (2015).¹
- **Land-based inland** – mid-point estimate of 0.5 million tonnes per annum (range 75,000 to 1.1 million tonnes per annum) based on plastics sampled in rivers. Source: Eunomia Research & Consulting Ltd. (2016)².
- **At sea sources** – mid-point estimate of 1.75 million tonnes per annum (range 0.3 to 3.25 million tonnes per annum). Source: Eunomia Research & Consulting Ltd. (2016).³ N.B mid-point 'rounded' to 1.75 Mtpa. The above cited report considers the amount of litter of all types, not just plastic, from at-sea sources. We therefore amend the total presented in that report on the assumption that 55% by weight is plastic, in line with Barnes, D.K.A., Galgani, F., Thompson, R.C., and Barlaz, M.

¹ Jambeck, J.R., Geyer, R., Wilcox, C., et al. (2015) Plastic waste inputs from land into the ocean, *Science*, Vol.347, No.6223, pp.768–771

² Eunomia Research & Consulting Ltd. (2016) Study to Support the Development of Measures to Combat a Range of Marine Litter Sources, Report for DG Environment of the European Commission

³³ Ibid.

(2009)⁴. The attribution of 65% to fishing sources and 35% to shipping sources is referenced in Eunomia Research & Consulting Ltd. (2016), and originally determined by Arcadis (2012);⁵

- **Microplastics** – mid-point estimate of 0.95 million tonnes per annum (range 0.5 to 1.4 million tonnes per annum). Source: Eunomia Research & Consulting Ltd. (2016),⁶ with figures for European emissions of primary microplastics scaled to a global level using PPP-adjusted GDP.

2.2 Where Do They Go?

As explained in Section 2.0, the right hand side looks at the *stock* of marine plastic (to which each year's annual flow keeps providing additional plastic). Accordingly, the percentages shown next to 'beaches', 'ocean surface' and 'sea floor' of 5%, 1% and 94% respectively relate to the proportion of the total amount plastic in the ocean that is found at each. It should not be read as meaning that, for example, within a year of new flows of plastic entering the marine environment, 94% will be on the sea floor.

There are many studies that attempt to quantify the amount of plastic that is present in each marine 'compartment'. This study attempts to bring all of this knowledge together to provide an overview of the current understanding of where the plastic may be. This is summarised in Figure 2 (in turn based on Table 1) for the compartments that can be quantified at present. Other major 'sinks' for the 'missing' plastic—plastic that was considered to be in the oceans until very recently—are thought to be Arctic sea ice and the deep sea sediments, both of which do not have enough data to allow quantification, but may contain considerable amounts of microplastics in particular.

Floating plastic appears in much lower concentrations than many people first thought. The highest surface water concentration of microplastic is in the North Pacific Gyre, but the maximum concentration (by item count) found through sampling in this area was only an average of 10 particles per square metre.⁷ This finding is particularly important as it puts in context the way in which plastic in the ocean is often portrayed as a 'garbage patch the size of Texas'⁸. This term is the cause of much misunderstanding in recent years.

The **highest**⁹ concentration (by weight) at the ocean surface, found in the North Pacific gyre, is 18kg¹⁰ of plastic (of all sizes) per km² and this is presented as the headline figure in the

⁴⁴ Barnes, D.K.A., Galgani, F., Thompson, R.C., and Barlaz, M. (2009) Accumulation and fragmentation of plastic debris in global environments, *Philosophical Transactions of the Royal Society B: Biological Sciences*, Vol.364, No.1526, pp.1985–1998

⁵ Arcadis (2012) *Economic assessment of policy measures for the implementation of the Marine Strategy Framework Directive*, accessed 15 October 2013, <http://ec.europa.eu/environment/enveco/water/pdf/report.pdf>

⁶ Eunomia Research & Consulting Ltd. (2016) op. cit.

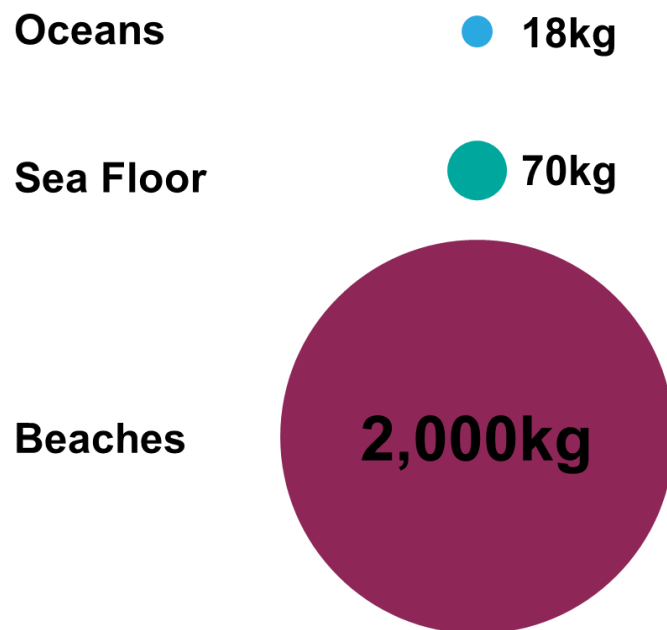
⁷ Eriksen, M., Lebreton, L.C.M., Carson, H.S., et al. (2014) Plastic Pollution in the World's Oceans: More than 5 Trillion Plastic Pieces Weighing over 250,000 Tons Afloat at Sea, *PLoS ONE*, Vol.9, No.12, p.e111913

⁸ <http://www.dailymail.co.uk/news/article-2141911/Scientists-Amount-plastic-Texas-sized-Great-Pacific-Garbage-Patch-increased-HUNDREDFOLD-1970s.html>

⁹ The average across all oceans is 0.74kg/km²

infographic, as this is the location where much attention has been focused in respect of removing plastics from the marine environment. However, the **average** concentration is 0.74 kg/km^2 . When compared with the estimated concentration of plastic on global beaches of $2,000 \text{ kg per km}^2$ we find that the concentration of plastics is considerably higher. As seen in Figure 1, the sea floor density is unexpectedly low considering the large amount of plastic thought to be there.¹¹ However, it has a considerably greater surface area than do beaches.

Figure 1 – Concentration of plastic per km^2



Note: 18kg/km^2 is the highest concentration found floating at or near the ocean surface, while the average is 0.74kg/km^2

Of the overall *amount* of plastic that is considered to be accessible (i.e. the plastic floating on the surface of the oceans and on beaches), less than 20% is accounted for by floating plastic. The relative amounts used in this calculation are:

- Floating - 268, 000 tonnes (0.27 million tonnes as shown in Table 1);
- Beach – 1,418,000 tonnes (1.4 million as shown in Table 1); and
- Sea Floor – 25,270,000 (25.3 million as shown in Table 1).

¹⁰ Eriksen, M., Lebreton, L.C.M., Carson, H.S., et al. (2014) Plastic Pollution in the World's Oceans: More than 5 Trillion Plastic Pieces Weighing over 250,000 Tons Afloat at Sea, *PLoS ONE*, Vol.9, No.12, p.e111913

¹¹ Again, please note that the ocean surface concentration of 18kg/km^2 is the highest recorded, which is why the relative concentrations, and relative amounts, of plastics at the ocean surface and at the sea floor do not appear to be consistently scaled.

Table 1. Estimate of Stock of Marine Litter from Environmental Sampling.

Plastic Location	Approach	Study Basis	Approximate expanse of marine location	Approximate average litter density	Global Estimate (Tonnes)
Floating	Sea surface sampling data and modelling.	Eriksen <i>et al.</i> (2014), C3zar <i>et al.</i> (2014) ¹²	361m km ²	0.74 kg/km ²	0.27 million ¹³
Beach	Beach sampling data prorated by length of coastline	The Ocean Conservancy (2012) ¹⁴ , Ryan <i>et al.</i> (2014) ¹⁵ , Smith <i>et al.</i> (2013) ¹⁶	1.4m km	1,013 kg/km (2,000kg/km ²)	1.4 million
Buried under beach sand	Proportion of beach surface to buried litter applied to beach sampling data.	Kusui and Noda (2003) ¹⁷	0.52m km	110 kg/km	0.057 million
Sea Floor	Sea floor sampling data prorated by area of sea surface, assumed to approximate area of sea floor.	Pham <i>et al.</i> (2014) ¹⁸	361m km ²	70 kg/km ²	25.3—65million
Total					27—66.7 million

¹² Cozar, A., Echevarria, F., Gonzalez-Gordillo, J.I., et al. (2014) Plastic debris in the open ocean, *Proceedings of the National Academy of Sciences*

¹³ Eriksen, M., Lebreton, L.C.M., Carson, H.S., et al. (2014) Plastic Pollution in the World's Oceans: More than 5 Trillion Plastic Pieces Weighing over 250,000 Tons Afloat at Sea, *PLoS ONE*, Vol.9, No.12, p.e111913

¹⁴ Ocean Conservancy (2012) *The Ocean Trash Index - Results of the International Coastal Cleanup (ICC)*, 2012, <http://www.oceanconservancy.org/our-work/marine-debris/2012-icc-data-pdf.pdf>

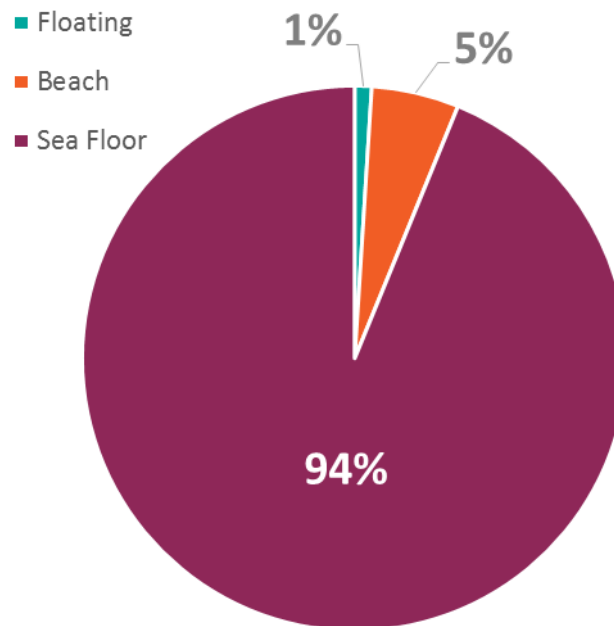
¹⁵ Ryan, P.G., Lamprecht, A., Swanepoel, D., and Moloney, C.L. (2014) The effect of fine-scale sampling frequency on estimates of beach litter accumulation, *Marine Pollution Bulletin*, Vol.88, Nos.1–2, pp.249–254

¹⁶ Smith, S.D.A., and Markic, A. (2013) Estimates of Marine Debris Accumulation on Beaches Are Strongly Affected by the Temporal Scale of Sampling, *PLoS ONE*, Vol.8, No.12, p.e83694

¹⁷ Kusui, T., and Noda, M. (2003) International survey on the distribution of stranded and buried litter on beaches along the Sea of Japan, *Marine Pollution Bulletin*, Vol.47, Nos.1–6, pp.175–179

¹⁸ Pham, C.K., Ramirez-Llodra, E., Alt, C.H.S., et al. (2014) Marine Litter Distribution and Density in European Seas, from the Shelves to Deep Basins, *PLoS ONE*, Vol.9, No.4, p.e95839

Figure 2 – Current Quantifiable Marine Environment Plastic Sinks



2.3 Plastic Stock Estimates Summary

We estimate the stock of marine litter by using data provided by sampling marine compartments. This is summarized in Table 1.

The approach to the calculations shown in Table 1 is described below.

2.3.1 Floating

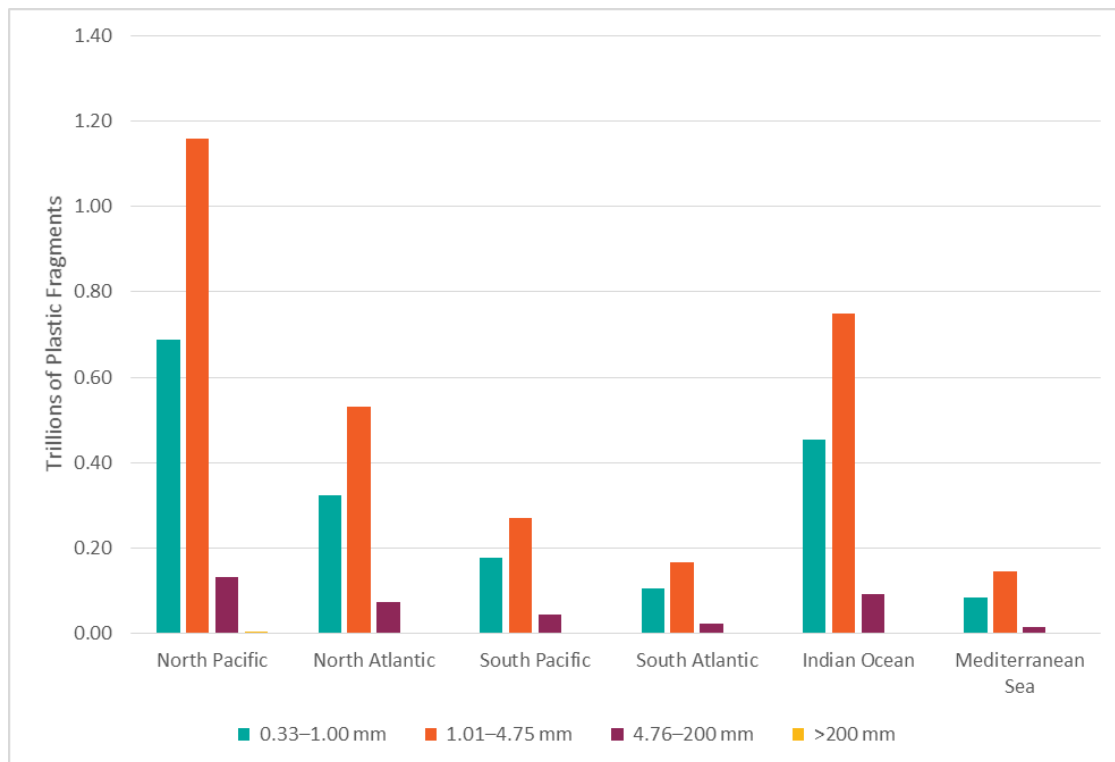
Sampling of sea water is usually conducted through the use of a surface-towed trawl where a net is towed by a vessel at a pre-defined depth. The size of the net opening, the length and depth of the trawl and the mesh size can all vary depending on the size and types of plastics that are being sampled. The most common net mesh size is 333 μ m (0.333 mm) although sometimes larger sizes are used to prevent clogging and if a large volume of water needs to be sampled.

A recent (2014) study headed by the Five Gyres Institute attempted to quantify the amount of floating plastics in the world's oceans in terms of both number and mass¹⁹ by using surface-towed trawls to collect plastic samples. The authors categorised plastics by size from 0.33 mm to those larger than 200 mm. Two size categories of microplastic were identified: 0.33 – 1.00 mm termed as 'small microplastics' and 1.01 – 4.75 mm as 'large microplastics'.

¹⁹ Eriksen, M., Lebreton, L.C.M., Carson, H.S., et al. (2014) Plastic Pollution in the World's Oceans: More than 5 Trillion Plastic Pieces Weighing over 250,000 Tons Afloat at Sea, *PLoS ONE*, Vol.9, No.12, p.e111913

As seen in Figure 3, however, there are far fewer particles in the small microplastics category when compared with the large microplastic category in all of the oceans studied.

Figure 3 - Total Particle Count of Plastic Floating in the World's Oceans



Adapted from Eriksen *et al.* (Five Gyres)

The study notes that, as most small microplastics are 'secondary' (they result from the breaking down of the larger items rather than from direct emissions of 'primary' microplastics), one would expect that the smallest sizes would be the most abundant. In fact, this was not the case. This suggests that at least one of the following is occurring:

- 1) The process of sampling the oceans meant that particles smaller than 0.33 mm could not be captured and there may be a significant number of that size or smaller;
- 2) There is a possibility that, in recent years, a significant increase in the release of larger plastic particles could have occurred, and that these have not had time to degrade into the smaller particles; and/or
- 3) There may be other sinks that remove the plastics from the ocean surface, such as degradation, ingestion by organisms, or, as identified by Barnes *et al.*,²⁰ a decrease in buoyancy due to bio-fouling from various organisms which can lead to the microplastics sinking to the seabed.

²⁰ Barnes, D.K.A., Galgani, F., Thompson, R.C., and Barlaz, M. (2009) Accumulation and fragmentation of plastic debris in global environments, *Philosophical Transactions of the Royal Society B: Biological Sciences*, Vol.364, No.1526, pp.1985–1998

The results of the study estimated that there are around **268,000 tonnes** of floating plastic of all sizes in the world's oceans. The surface area of the oceans²¹ is 361 million km²,²² so the average concentration is 0.74kg/km²

2.3.2 Beach

Most litter surveys conducted on beaches are done in situ by hand collection and sorting and for this reason tend to have a lower size limit of 0.5-25mm. As a result, they may not include mesoplastics and tend not to include microplastics, which are too small to practically assess in the context of a clean-up without considerably adapting the methods used. If they report data standardised to geographical units at all, many surveys do so in terms of *items* per kilometre rather than weight. However there is a global survey that does estimate tonnages per unit length – the International Coastal Clean-up (ICC). In 2012, their volunteers collected approximately 4,513 tonnes of beach litter from 26,700km of coast.²³

This is a large amount, compared with the global estimates of floating litter (268,000 tonnes²⁴), considering that the clean-ups covered only 1.9% of a world coastline of 1.4 million km.²⁵ *Pro rata* calculation gives an estimate of 236,331 tonnes of beach litter globally, as shown in Table 2.

Table 2. Stock of Plastic Beach Litter, Global Estimate – tonnes

Data source	Marine Litter (kg)	Length Coastline Cleaned (km)	Marine Litter (kg/km)	Total Coastline (km)	Total (tonnes)
Beach litter (ICC) (2012)	4,513,449	26,709	169	1,398,504	236,331

Furthermore, there are reasons to think that beach litter estimates may be underestimates. The ICC is undertaken on an annual basis. Although litter on beaches will to some extent represent an accumulation over time, beach cleans can occur more frequently – up to four times a year (as per the OSPAR beach litter monitoring cycle²⁶). Therefore the ICC estimates may not reflect the full annual accumulation.

Additionally, papers looking at the effect of sampling interval on estimates of accumulation rate of litter on beaches found that longer sampling intervals lead to an underestimation of the daily accumulation rate, because some litter gets washed back out to sea. Collecting

²¹ CIA World Factbook <https://www.cia.gov/library/publications/resources/the-world-factbook/geos/xx.html>

²² CIA World Factbook <https://www.cia.gov/library/publications/resources/the-world-factbook/geos/xx.html>

²³ Ocean Conservancy (2012) *The Ocean Trash Index - Results of the International Coastal Cleanup (ICC)*, 2012, <http://www.oceanconservancy.org/our-work/marine-debris/2012-icc-data-pdf.pdf>

²⁴ Eriksen, M., Lebreton, L.C.M., Carson, H.S., et al. (2014) Plastic Pollution in the World's Oceans: More than 5 Trillion Plastic Pieces Weighing over 250,000 Tons Afloat at Sea, *PLoS ONE*, Vol.9, No.12, p.e111913

²⁵ CIA World Factbook: ~1.2 million km; World Resources Institute: ~1.6 million km; cited in https://en.wikipedia.org/wiki/List_of_countries_by_length_of_coastline

²⁶ OSPAR, UNEP, and KIMO (2007) *OSPAR Pilot Project on Monitoring Marine Beach Litter: Preventing a Sea of Plastic*, 2007, http://qsr2010.ospar.org/media/assessments/p00306_Litter_Report.pdf

litter daily increased the estimate of the daily accumulation rate compared with estimates based on a similar overall time period where monitoring was carried out weekly or monthly.

One study comparing daily to weekly monitoring intervals found that daily sampling collected 1.7 times more items by weight and 2.5 by count on average, and this was much higher for lighter items.²⁷ A study comparing daily with monthly monitoring periods found accumulation rate by count increased by a factor of 10; a sampling interval of 6 months gave an estimate of daily accumulation that differed by a factor of 20.²⁸ This would be roughly equivalent to the amount of litter collected on a daily basis for 6 months being around 8 times greater than if litter was collected only at 6 month intervals. The 'turnover' rate of litter that determines these relationships would vary widely depending on not only the item characteristics but also the characteristics of the beach.

These studies indicate that quarterly or yearly monitoring will underestimate the amount of stranded beach litter by a potentially large margin. Choosing an approximate midpoint of 6 for the 'underestimation factor' caused by long sampling periods would increase our estimate of beach litter to **1,418,000 tonnes**. We then apply the conservative assumption that the depth of the beach (i.e. the distance between the waterline and the land behind the beach) cleaned by the volunteers in the ICC is 500m, meaning that the 1,013kg/km converts to approximately 2,000kg/km².

2.3.3 Sea Floor

Visual surveys and trawls of the sea floor are the most relevant source of data for macrolitter in this marine compartment; for microplastics, sediment sampling is the most relevant technique. By weight, data is only available where trawling is used as the sampling method, for there is a dataset from the Mediterranean implemented on a "by-unit-area" basis. The densities were 70-180kg per km² generally with a maximum of 400+/-180kg per km² in the worst affected area.²⁹

Using global figures on sea area (361 million km²),³⁰ and making the assumption that the area on the sea-floor is roughly equivalent to the area on the sea surface, using the low range for debris of 70-180kg per km² gives figures of **25.3-65m tonnes** of debris globally (see Table 3); while using the higher density of 400kg per km² gives a global estimate of 144.4m tonnes. The amount of sea floor debris is highly dependent on physiography of the area sampled; therefore these estimates are somewhat crude.

²⁷ Ryan, P.G., Lamprecht, A., Swanepoel, D., and Moloney, C.L. (2014) The effect of fine-scale sampling frequency on estimates of beach litter accumulation, *Marine Pollution Bulletin*, Vol.88, Nos.1–2, pp.249–254

²⁸ Smith, S.D.A., and Markic, A. (2013) Estimates of Marine Debris Accumulation on Beaches Are Strongly Affected by the Temporal Scale of Sampling, *PLoS ONE*, Vol.8, No.12, p.e83694

²⁹ Pham, C.K., Ramirez-Llodra, E., Alt, C.H.S., et al. (2014) Marine Litter Distribution and Density in European Seas, from the Shelves to Deep Basins, *PLoS ONE*, Vol.9, No.4, p.e95839

³⁰ <https://en.wikipedia.org/wiki/Ocean>

Table 3. Estimates of Sea-floor Litter

Litter Density	Global Sea-floor Litter (tonnes). Sea area = 361,000,000km ²
70kg/km ²	25,270,000
180kg/km ²	64,980,000
400kg/km ²	144,400,000

3.0 Conclusions

There are considerable limitations to the data available on the flows and stocks of marine plastic litter, and there would be significant value in further studies, including examination of the stocks of marine plastics for which we were unable to find useable data (e.g. the amount locked up in sea ice, or eaten by sea life). Nevertheless, the very significant scale of the differences in size between the different stocks and flows, combined with the conservative assumptions utilised, mean that the broad shape of the findings in this report are likely to be confirmed by further research.

As policy makers, campaigners and the public increase their awareness of this topic, it is important that action to address marine litter is focused in the areas where it will be most effective. We hope this study helps to inform discussion so that the problem can be tackled as quickly and thoroughly as possible.