


DISCUSSION

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Are litter, plastic and microplastic quantities increasing in the ocean?

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Abstract

Whilst both plastic production and inputs at sea have increased since the 1950s, several modelling studies predict a further increase in the coming years in these respective quantities. We compiled scientific literature on trends in marine litter, consisting largely of plastic and microplastics in the ocean, understanding that monitoring programs or assessments for these aspects are varied, frequently focusing on limited components of the marine environment in different locations, and covering a wide spectrum of marine litter types, with limited standardization. Here we discuss how trends in the amounts of litter in the marine environment can be compared with the information provided by models. Increasing amounts of plastic are found in some regions, especially in remote areas, but many repeated surveys and monitoring efforts have failed to demonstrate any consistent real temporal trend. An observed steady state situation of plastic quantities in many marine compartments and the fate and transport of plastic in the marine environment remain areas for much needed further research.

Keywords: Plastic pollution, Marine litter, Microplastics, Trends, Monitoring

Introduction

Plastic cycling in the marine environment and trends in marine litter quantities over time remain important unanswered questions. While it is well established that vast quantities of plastic (a subset of marine litter) enter the ocean annually [19], it remains difficult to assess actual trends in the flux of plastics to the ocean simply because the seafloor is a major sink for marine litter, plastic and microplastics [3, 20, 36, 47]. Currently, there are no reliable estimates for either the quantity of plastics sinking to the seafloor, or for the potentially significant input of microplastics via atmospheric deposition [28]. Moreover, the sources of plastic in the marine environment are too numerous to account for and research on their impacts on the marine environment is ongoing.

It is now a common assumption that there is an excessive amount of plastic in the ocean. This fact, sometimes exaggerated, has been used by stakeholders and Non-Governmental Organizations (NGOs) to advocate for policies and economic solutions to reduce plastic [32]. Though there is a great need for systemic changes in plastic production, use and recycling strategies so as to reduce the volume of plastic in the ocean, it is still unknown whether the quantities of litter, plastic and microplastic abundances are currently actually increasing in the ocean.

While both plastic production and inputs to the sea have increased worldwide [5, 14, 19], plateauing levels of plastics measured at sea could be explained through the fragmentation of larger pieces not previously accounted for, or through their transfer from local to remote areas where measurements are scarce, especially in the deep sea. The question on how physical, chemical or biological degradation may limit the increase of plastics at

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sea is not yet resolved. Several modelling studies, based on waste production or extrapolated riverine inputs, predict increasing inputs of plastic to the ocean [11, 14, 17, 19, 21, 26, 27], that could be at least partially offset in the future by societal reduction measures [5, 23].

Discussion

A closed mass balance of all marine litter in all seas would be needed to reliably converge on temporal trends. However, such an evaluation is not possible at this stage since fluxes of litter between various components of the marine system, especially rates of sinking and mechanisms of degradation and persistence, are not fully understood. Existing data, however, may help identify the important questions to address. We compiled scientific literature on global trends in marine litter amounts through an extensive search in science databases (See Supplementary material S1 on methods and S2 for a summary of references used). These monitoring programs or assessments most often report on the results of single surveys, discrete water samples, sediments or biota, and cover a wide spectrum of sizes, types, shapes, polymer types and colors, with limited data on nanoplastics. These differences in research techniques and methodologies can mask or amplify trends in marine plastic abundance. For instance, sampling for microplastics with nets often misses fibers and smaller-sized microplastics [34, 40], while studies isolating smaller fractions from water give counts of these materials that are not broadly consistent. Minimum cutoff sizes of microplastics measured in water or sediments differ between studies and are therefore difficult to compare. Plastics recorded in water and sediments are typically significantly larger than microplastics recorded in marine biota. These smaller microplastics that go undetected may cause impacts in marine organisms [15] and potentially lead to in human health effects [2]. Counting particles under a microscope has limitations. Smaller sizes can be missed and it is easy to confuse natural and polymer microfibers. In contrast, techniques such as Raman and FTIR spectroscopy coupled to microscopy can identify smaller-sized microplastics and characterize the nature of the polymers. If, over time, methodologies shift to standardized methods that may include using grab samples or smaller mesh nets or standardized size fractions, increasing attention to clean methods to reduce contamination from air, and harmonised analytical approaches, there will be greater comparability across studies to ascertain trends. Studies from different locations or time periods cannot currently be accurately compared.

When comparing modelling results with empirical data, a temporal increase in marine litter amounts was demonstrated in a limited number of studies for remote

parts of the ocean, such as remote islands, the Antarctic [3], the Indian Ocean [10] and the South Atlantic [37], for plastic ingested by south Atlantic petrels [35], and in specific oceanographic features, including converging currents above the Arctic circle [41]. Interestingly, since the 1950s baseline, floating microplastics at sea increased exponentially each decade until the 2000s [42]. Very recently, Wilcox et al. [45] revisited the data on floating microplastics in the North Atlantic Ocean (which did not exhibit any trend from 1986 to 2008, [24]), and Brandon et al. [6] analyzed microplastics in sediments from California collected over a span of 175 years. Both studies suggested an increase in the amounts of microplastics, proportional to plastic production worldwide, as for a local study with very limited samples in the bay of Sydney [46]. However, most of the work based on regular and periodic monitoring surveys has not demonstrated any real trend in these quantities.

For large debris on beaches, an absence of temporal trend was demonstrated for macroplastics in the North Atlantic, between 2001 and 2011 [38], in Chile, between 2006 and 2016 [16] and for data from cleanups in Taiwan, between 2004 and 2016 [44]. An absence of temporal trends was also observed for large floating debris in the Balearic Islands between 2005 and 2015 [7] and in China, between 2007 and 2014 [49]. In addition, collections of marine litter by Continuous Plankton Recorders [33] showed relatively unchanged amounts trapped annually in the North East Atlantic since 2000, following a steady increase since the 1950s.

In seafloor litter studies, no change in plastic pollution was measured in Spain between 2007 and 2017 [12] nor in the North Sea [30]. A slight increase in seafloor plastics was observed in recent years in the Baltic (excluding fishing gear) [48], while results from observations in France, between 1995 and 2017 (23 years), showed mixed trends, of decreasing amounts between 2000 and 2013 and of increases since 2013 [13]. No trend was identified in Chinese waters for sea floor litter between 2007 and 2014 [49], with a large variability in plastics concentration and from data collected during regular State monitoring between 2011 and 2018 [31]. In contrast, a decrease in total seafloor litter was measured between 2007 and 2017, in both the Alboran Sea [12] and the northern Adriatic, [39], without significant temporal trends for plastic in the remaining Adriatic.

For microplastics, floating particles were found at similar levels between 2005 and 2014 in East Greenland [1], in the North Atlantic Subtropical Gyre between 1986 and 2008 [24] and in the North Pacific Subtropical Gyre between 2001 and 2012 [25]. In addition, no changes in floating microplastics ($>150\ \mu\text{m}$) were detected between 1987 and 2015 in the Baltic Sea [4], between 1987 and 2012 in the North Atlantic

subtropical gyre [43] and between 2001 and 2012 in the North Pacific Subtropical gyre [25]. For ingested large debris, constant levels were also demonstrated for stranded cetaceans recorded from Irish waters between 1990 and 2015 [29], and in western Mediterranean sea turtles between 1995 and 2016 [9].

Finally, understanding that quantifications of small ingested microplastics, by mass, may range from 1 to 2% to 30–90% of control tests that are positive [18, 22], constant levels were also demonstrated for ingested microplastics by little auks in the Arctic [1], in herring and sprats from the Baltic sea between 1987 and 2015 [4], in deep sea benthic invertebrates between 1976 and 2015 [8], and in fulmar (*Fulmarus glacialis*) from the North Sea [43].

Conclusion and future perspectives

Most studies indicate constant amounts of litter in coastal marine systems in recent years until 2019. The increase in plastic quantities observed in remote areas over time could therefore be interpreted as a long-term transfer of litter from directly affected areas to regions where human activity is either extremely reduced or non-existent. Nevertheless, while the predicted total global amount of plastic litter is increasing, as suggested by models, the apparent steady state situation of plastic quantities observed in coastal systems challenges our ability to predict plastic sources and fate. More standardization and coordination is needed before we can reliably report on trends in plastic waste. Decreasing marine temporal trends is possible for specific types of plastics, subject to societal reduction measures, as is the case for industrial pellets, which have received much consideration in regional action plans following changes in industrial practices. Formulating scenarios on the future effect of proposed management measures [5, 23] is reminiscent of debates starting many years ago around climate change, with model predictions identifying the need for data, leading to longer-term observational efforts. Until the mechanisms behind the apparent steady-state amounts of plastics recorded in surveys across the marine environment are better understood, the identification of possible trends will remain a challenge. There remain many data gaps and uncertainties on the rates of degradation, burial and transport of plastics in the marine domain. Only more scientific research can provide quantification of the plastic pollution problem in marine systems to begin to fully address its sources, thus identifying solutions which must come from the international community through a global ocean governance framework. The basic questions about where marine litter is, goes, how it degrades and cycles in the ocean have definitely not been fully answered and in the upcoming UN Decade for Ocean Sciences, this should definitely be a priority.

Supplementary Information

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Additional file 1.

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Authors' contributions

The initial version was drafted by FG, then discussed, corrected and finalized by all authors. The author(s) read and approved the final manuscript.

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