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Microplastic size matters—Report every particle

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Microplastic size largely determines how they move, how they interact with ecosystems, where they ultimately end up, and their environmental impacts. Despite this, particle size information continues to be reported sporadically. Image credit: Shutterstock/Real People Images.

More than two decades of research have established microplastics (those measuring 1 μm to 5 mm in size) as ubiquitous environmental contaminants (1). And as legacy plastics already in the environment continue to fragment and shed smaller particles, microplastic concentrations are projected to increase. Even under optimistic scenarios in which governments and communities reduce both primary plastic production and the influx of new debris, this upward trend is expected to persist well beyond the United Nations Environment Programme's 2040 target for ending plastic pollution (2).

Reported microplastic abundances vary substantially among studies, even when sampling the same environmental compartment. In the oceanic water column, for example, measured abundances span eight orders of magnitude (10^{-4} to 10^{4} particles/m^3) across different locations and depths (3). Some of this variation likely reflects genuine spatial and vertical heterogeneity in microplastic distribution. Unfortunately, large differences in sampling and analytical methods make it difficult to separate environmental variability from methodological effects, hindering direct comparison across studies. Incompatible research findings limit geographic comparisons, temporal trend analyses, and large-scale syntheses (3). Ultimately, these inconsistencies constrain researchers' mechanistic understanding of microplastic transport and distribution, obscure their environmental fate, and introduce substantial uncertainty in quantifying their ecological and biogeochemical impacts.

In recent years, researchers have attempted to harmonize methodologies (refs. 4–6; Fig. 1). But achieving a global methodological consensus on microplastic

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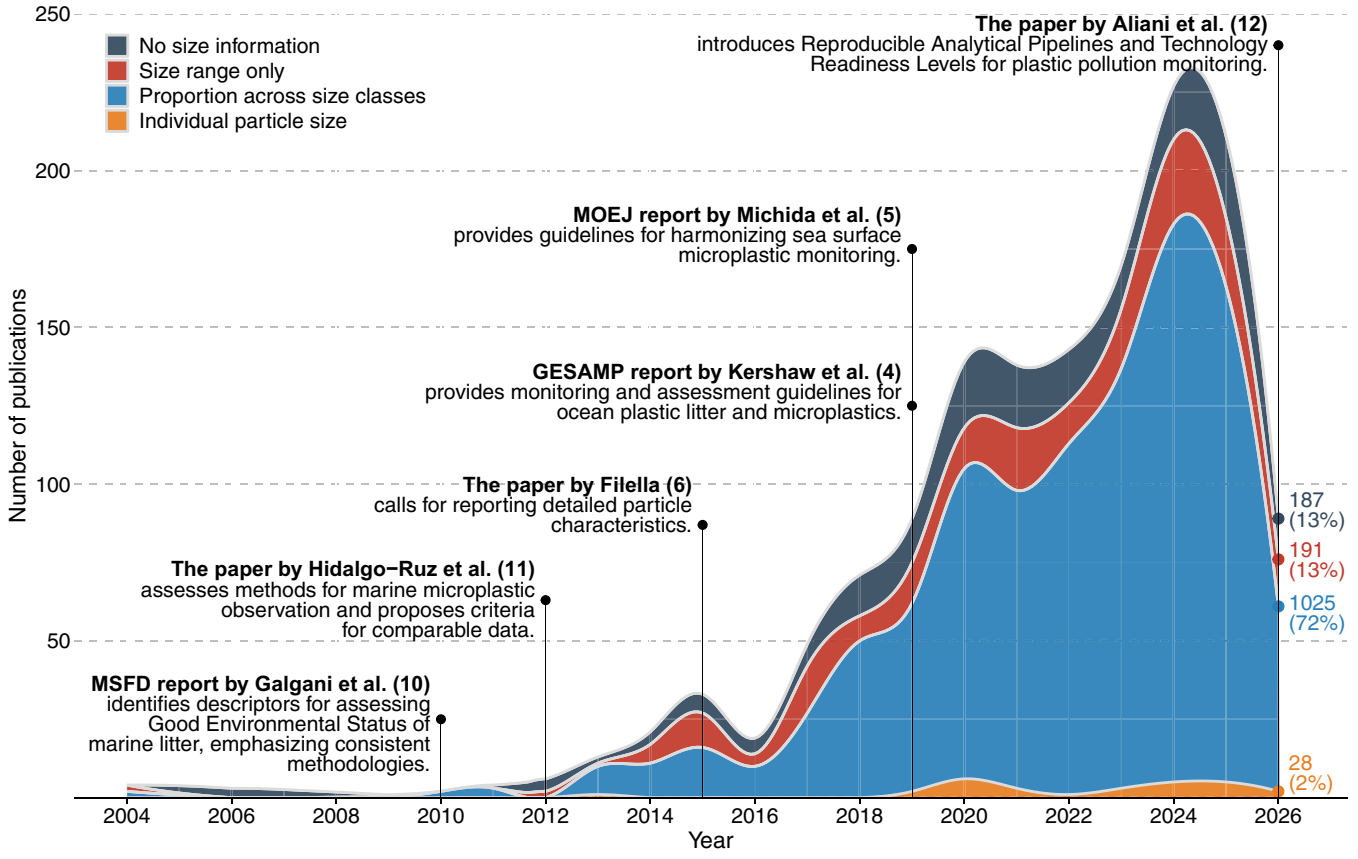


Fig. 1. How scientists have reported the sizes of marine microplastics over 2004–2026. This graph categorizes 1,431 studies by their reporting method (data are in the *SI Appendix*). The wide area in the blue section (72%) represents that the vast majority of researchers chose to sort microplastics into different size groups, whereas the orange area (2%) represents raw, unbinned size reporting. The remaining studies either give only a minimum and maximum (Size range only; red, 13%) or leave out size data entirely (No size information; gray, 13%). Annotations point to key publications that helped standardize microplastic research methods.

monitoring remains resource-dependent and time-intensive (3). In particular, the high costs of advanced analytical approaches, such as micro-Fourier transform infrared and micro-Raman spectroscopy, together with the limited availability of long-term monitoring networks, sampling platforms (e.g., research vessels), and collection equipment, restrict the production of consistent global data.

Particle size strongly influences how microplastics move and sink in the environment, as well as their transfer through food webs and potential toxicity. However, over 70% of published studies aggregate particle counts into arbitrary size bins rather than reporting individual particle size, thereby losing information needed to resolve size-dependent environmental processes (Fig. 1). Here, we argue that the mandatory reporting of raw, individual particle dimensions, at minimum the longest particle length, provides a resource-independent, immediately implementable solution to the data comparability crisis. This allows scientists to build particle size distributions (PSDs) that show microplastic concentrations at any given size (7). Such PSDs facilitate comparisons among studies and provide a more consistent basis for modeling the transport, fragmentation, and environmental fate of microplastics. Given the pervasive nature of microplastic pollution, we need immediate and realistic solutions. Comprehensive reporting of microplastic size is a crucial step forward.

Barriers to Data Comparability

Microplastic particles are inherently heterogeneous, comprising diverse polymers, sizes, densities, shapes, colors, and associated chemical cocktails (3). This complexity, together with differences in research objectives, laboratory capacities, and environmental conditions, has led researchers to use a wide range of approaches to collect, process, and analyze microplastics. For example, studies targeting different plastic sizes or sampling depths and hydrodynamic conditions may require different sampling strategies, while laboratory equipment and expertise can limit the particle sizes that can be reliably identified. These methodological choices determine which particles are captured and detected and, therefore, influence the reported abundance and size distribution at a given site, limiting geographical and temporal comparability (8). In regions with high particle loads, net sampling may be operationally practical because it efficiently collects abundant particles, but relatively large mesh sizes may preferentially retain larger microplastics. In contrast, filtration-based approaches can capture smaller particles but may be more prone to clogging, limiting the sampling volumes.

Inconsistent reporting further limits comparability, including differences in how particle size, abundance, polymer type, and other characteristics are categorized and reported, as well as the limited availability of raw data (9). Reporting particle-level

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data can be implemented without additional cost. And yet, despite more than 15 years of efforts to harmonize microplastics research, substantial differences remain across sampling, processing, analysis, and reporting (refs. 4–6, 10–12; Fig. 1). Achieving methodological uniformity at every stage remains difficult because researchers must adapt their methods to different research questions, environmental conditions, particle sizes, and available resources.

Despite its fundamental importance, raw microplastic size reporting is rare, even as the demand for detailed multidimensional characterization grows.

What Particle Size Regulates

Particle size is a fundamental control on the transport and fate of both natural and microplastic particles in aquatic environments (13). Microplastics' size influences their response to currents and turbulence, suspension, aggregation, incorporation into marine snow, sinking, and uptake by organisms. Consequently, particle size confers critical information related to microplastic dynamics, environmental fate, and impacts and is relevant to researchers and policymakers.

To a first order, particle size is a key determinant of microplastic behavior in fluids. It governs whether movement is dominated by Brownian motion, gravitational settling, buoyancy, or advection. Brownian motion becomes increasingly important below several microns because small particles are more strongly affected by random collisions with surrounding water molecules; the movement of larger particles, meanwhile, is influenced by different transport modes. Studies suggest that both small plastics (from nanoscale to a few-micron-scale) and plastics in the millimeter-size range exhibit high riverine retention, driven by Brownian diffusion-induced aggregation and sedimentation, respectively (14).

Recent research combining more than 6,000 observations of microplastic-aggregate interactions found that incorporation into aggregates decreases with increasing particle size, from 97% for particles < 20 μm to 9.7% for particles > 162 μm. These findings underscore the importance of individual particle size data for modeling microplastic transport in aquatic systems (15).

Size also influences the sinking rates of nonbuoyant microplastics. For example, a 1-mm nylon particle coated with a 5-μm diatom layer is estimated to sink more than 1,500 m in a single day in seawater, whereas a 25-μm nylon particle sinks only about 2.9 m in a year (16).

These differences in sinking rates affect the vertical distribution and residence time of microplastics in the water column. Observational and modeling studies show that smaller water-column microplastics (<100 μm) are more evenly distributed than larger particles. In addition, microplastic retention at sharp density gradients is also strongly size-dependent (3).

With respect to the interactions with organisms and cells, microplastic size has long been recognized as an important factor. Particle size determines whether an organism can ingest a plastic particle. Once ingested, a particle's toxicity is heavily influenced by its size. Larger microplastics generally remain in the digestive tract and cause food dilution, whereas particles smaller than 80 μm can translocate into other tissues. This translocation probability increases dramatically as particle sizes decrease (9).

Reporting Particle Size

When individual microplastic sizes are reported, these data can be used to construct PSDs and model their size-dependent patterns (6, 7). With sufficient size data, researchers can combine measurements from different studies and analytical methods to reconstruct PSDs across a broad size range, providing a consistent basis for comparing microplastic distributions among environments (17, 18). This approach also avoids biases introduced by arbitrary size-bin definitions, which can substantially affect estimated PSDs (19, 20).

Despite its fundamental importance, raw microplastic size reporting is rare (Fig. 1), even as the demand for detailed multidimensional characterization grows (6, 9, 20). Our review of 1,431 publications on marine microplastics (2004–2026) reveals that size data are reported primarily as bulk proportions within disparate size categories. Remarkably, while individual particle-level size data are the foundation for generating ideal PSDs, only 2% of these studies provided this level of detail over the past 20 years (Fig. 1). Although properties such as shape and density are equally important, size can be more easily measured and is a part of nearly every study. To reduce the complexity, size reporting should be prioritized; yet, the current lack of individual particle-level data compromises the utility of observational studies and prevents the construction of PSDs.

To address the microplastic size reporting challenge, we propose systemic shifts in how microplastics size data are measured, reported, constrained, and improved.

Mandatory Particle Size Reporting

Currently, there is no universally accepted way to define microplastic size, and many studies do not report how particle size was measured. When a method is specified, the longest particle dimension, also referred to as the maximum length or maximum Feret diameter, is most commonly reported (6). We urge scientific journals and funding agencies to require researchers to share exact measurements for individual particles and clearly explain their methods, rather than grouping data into size categories. At a minimum, studies should report the maximum Feret diameters of every single microplastic found. Sharing these raw data allows scientists to build accurate PSDs, facilitating robust cross-study comparisons.

In addition, studies must clearly report the smallest microplastic size that their methods can reliably detect. Without this information, it is difficult to know if a sharp decrease in small particles reflects an environmental reality, rather than the detection limits of the analytical approach. For instance, if microplastics counts drop sharply near the smallest size that a method can detect, the apparent decline may reflect a limitation of the method rather than a true environmental pattern (7, 17, 20).

Beyond length, we encourage the inclusion of additional particle measurements, such as area and perimeter. These

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parameters are vital for converting abundance-based PSDs into mass-based PSDs. Because particles of different sizes travel and sink differently, mass size distributions accurately calculate how much weight is held within each size category. Understanding this weight distribution is the key to tracking where the plastic has gone and, ultimately, balancing the global plastic mass budget (13, 20).

All data must adhere to FAIR principles (Findable, Accessible, Interoperable, and Reusable) so that they can be globally and reliably integrated into diverse models and ecotoxicological experiments. Finally, we urge major environmental journals to mandate the upload of raw particle size data. Journals can establish mechanisms allowing authors to upload raw data as formal updates to their past publications. These data files (CSV or JSON files) can be issued a permanent digital ID, ensuring that the exact particle measurements remain citable and directly linked to the original paper.

Data Management

To move beyond fragmented reporting, the microplastics research community must develop a centralized, public repository for standardized size parameters. Recently, several significant databanks have been established, including the Atlas of Ocean Microplastics (AOMI), supported by the Ministry of the Environment, Japan (21); the National Oceanic and Atmospheric Administration National Centers for Environmental Information (NCEI) Marine Microplastics (22); and the European Marine Observation and Data Network (EMODnet) marine litter database for European waters, supported by the European Union (23). For example, AOMI allows researchers to visualize sea surface microplastic abundances on a global scale, greatly enhancing its utility for the public and decision-makers to inform and assess the progress of plastic waste reduction efforts. AOMI encourages researchers to offer microplastic concentrations across two specific size categories under 5 mm. While these platforms have developed protocols to harmonize disparate abundance data—for example, converting diverse metrics into common units, such as pieces/m^3 or mass/m^3—they largely function as archival repositories that accept datasets "as-is." Currently, these databases lack rigorous "quality gates" for comprehensive and individual particle parameters.

To overcome these limitations, microplastics databases should mirror the successful, high-integrity data-sharing frameworks utilized by the marine geochemistry community. Specifically, we argue for a data management framework inspired by the GEOTRACES protocol, which maintains a rigorous focus on the characterization and intercalibration of marine natural particles (24). In the GEOTRACES model, data are only admitted to a global product after passing through an international standard and intercalibration committee. Such a model could ensure that microplastics data are not just archived, but are also scientifically validated. Finally, as established in the "omics" communities, uploading raw data to a curated database and obtaining an accession number should be a mandatory prerequisite for publication in academic journals. This ensures that the data are both preserved and immediately publicly available.

These steps represent much more than an accounting or categorizing exercise. By focusing on microplastic size, we can organize chemical and morphological variables into a coherent framework for assessing environmental fate and risk. Such a framework will become increasingly critical as microplastic pollution intensifies and its implications come into focus. Microplastics pose interconnected threats to human, animal, and environmental health, a reality that lies at the heart of the "One Health" concept. Applying our recommendations consistently across water, air, soil, and wildlife research can enhance our understanding of how microplastics disperse and, ultimately, how they impact our health.

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