Improving microplastics source apportionment: a role for microplastic morphology and taxonomy?

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Microplastics have emerged as a high-profile contaminant issue due to their widespread occurrence in aquatic environments. Environmental conservation agencies are gaining a better understanding of the issue and are beginning to implement strategies to reduce microplastic contamination. As a scientist with the Ontario Ministry of the Environment and Climate Change in Toronto, Canada tasked with improving our knowledge of the microplastics issue with respect to their sources into and impacts upon the Laurentian Great Lakes, I’ve had the opportunity to interact with policy staff, environmental compliance staff, stakeholders and members of the public. These interactions have helped define the information needs from our microplastic monitoring and research activities to best inform policy development and management activities. These informational needs should be considered as we work together to refine the approaches and protocols employed to conduct assessments of the occurrence and impacts of microplastics. It has become clear that more detailed source apportionment information is needed to provide direction to resource managers for implementation of measures to reduce microplastic contamination.

Researchers from a variety of scientific disciplines have been involved in studies on microplastics, from limnology and oceanography to toxicology, and marine biology to analytical and polymer chemistry, to name a few. Educators and citizen scientists have also been instrumental in raising awareness about microplastic contamination. Such diversity in disciplines has contributed to the range of approaches and methods used to collect, characterize, and report on the presence and impacts of microplastics in the environment. These disciplines can learn from each other to refine, enhance, and standardize the protocols used while advancing the assessment science and monitoring of microplastic contaminants. With a background in environmental analytical chemistry, it is perhaps no small irony that here I suggest lessons from the biological sciences to help us improve our abilities in identifying source contributions of microplastics. To add to the irony, it was recently posited by a colleague in the Great Lakes community, who has a background in limnology and microbiology, that lessons from trace contaminant analyses (e.g. metals) can improve methodologies for sampling and quantitative analyses of microplastics.

In response to the issue of microplastics contamination of aquatic environments, policy advisors and resource managers are asking variations of the following questions:

1. What and how much microplastics are in our waters?
2. Where are the microplastics coming from?
3. What harm do the microplastics cause?
4. What can be done to reduce the presence of microplastics in the environment?

Studies of microplastics to date, and those underway, aim to answer these questions and to help guide policy development and implementation of resource management activities to address the issue. Methods of analysis need to ensure that they provide the appropriate information, rigor, and accuracy for responding to these questions, informing policy and management actions, and measuring the effectiveness of those actions.

Methods for the sampling of microplastics in water and biota as well as initial characterization are largely based on techniques used in limnology/biology. These include the sampling of plastics with neuston nets used for phytoplankton/zooplankton collections, followed by microscopy to separate and tentatively identify the particles. In an effort to standardize protocols and increase efficiency, chemical digestion procedures to isolate particles² and analysis techniques exploiting the unique
bond chemistry of the various polymers [e.g. Fourier transform infrared (FTIR) and Raman spectroscopy] are becoming more integrated into quantitative microplastic assessments. Quality assurance procedures, adopted from approaches used in trace chemical contaminant analyses (e.g. standard additions for recoveries, blank samples) are improving data quality. The influences of experiences from the various disciplines leading research on microplastics are apparent as progress is made towards standardized practices and procedures.

Many of the sampling, extraction, and analysis-method improvements and considerations discussed within this themed collection will contribute to more efficient and effective monitoring and assessment of microplastics within the aquatic environment. Studies, and the methods used to conduct them, are progressing from initially documenting occurrence in open-ocean environments far from sources, to now gaining an understanding of the pathways they take to aquatic systems, their fate within them, and the exposure conditions faced by organisms contained therein. In doing so, studies have moved to closer proximity to source inputs, namely nearshore waters, riverine systems, stormwaters, and municipal wastewaters that are adjacent to or within the developed population centers where the plastics are so widely used. This progression means that there are now stronger links to the specific material sources, and it is now necessary to provide specific information on the contributions of such sources, so that policy advisors and resource managers can implement strategies to address them.

Enhancing source apportionment

Microplastic reports generally provide an indication of the types of particles found across broadly defined categories, and may include the likely sources of a few examples. Chemical analyses which confirm the polymer identity of the particles are important for providing accurate data on microplastic abundance. However, they do not necessarily provide a strong indication of a particular source, especially given the wide use of several polymers such as polyethylene, polypropylene, and polystyrene. For other niche-use plastics, polymer identification may help to pinpoint particular sources based on their more limited range of uses. Source apportionment efforts would benefit from the further development of a standardized particle classification scheme, perhaps adopting approaches used in the classification of organisms, establishing the taxonomy of plastic particles based on morphology.

The current typical classifications, as referenced in reviews and studies in this themed issue and in studies in the Great Lakes region, are based on particle morphology and include fragments, fibers, foam, film and pellets. As a higher plastic taxonomic level these classifications may be sufficient for summary purposes, although some clarification of terminology is required. For example, pellets and beads have been grouped together or used interchangeably. Given that pellets tend to refer to pre-production or feedstock pellets for the manufacture of plastic goods, whereas beads usually refer to microbeads like those used in exfoliating face and body washes, the separation of these categories into ‘pellets’ and ‘microbeads’ is merited.

A more detailed level of classification based on morphology can then be established within the higher-level categories where possible to better reflect the origin and use of the microplastic particles, helping to delineate particular source sectors. For example, subdivision of the pellet classification into virgin pre-production pellets and those produced through plastics recycling operations could be considered. Similarly, films may have attributes that allow distinction between consumer uses (e.g. single-use plastic bags, candy bar wrappers) and perhaps other sectors like building construction (vapour barrier) and agriculture (row cover, greenhouses). Further development of the foam classification may allow distinction between expanded polystyrene (food containers, protective packaging, insulation board), extruded polystyrene (insulation board), and other types of foam (e.g. polyurethane foam). The fiber classification may be more difficult to subdivide, especially as there remain challenges in distinguishing between synthetic, artificial (anthropogenic derived from natural materials), and natural fibrous material. Microbeads (spherical and irregular) have multiple uses and sources, but are most often associated with personal care products (Fig. 1). The fragment category consists of particles resulting from the breakdown of litter and debris, but it can also become something of a ‘catch-all’ for otherwise undefined particles from various sources, including irregularly-shaped microbeads.

Fragments can be a dominant portion of the distribution of microplastics in environmental samples. Together with the wide variety of sources that contribute fragments, this suggests that further morphological classification could provide more information on particular microplastic sources, especially when sampling occurs relatively close to source areas, thus reducing the amount of weathering that particles experience. The morphology of broken-up debris/litter particles often includes angular, well-defined edges [Fig. 2(a)]. Sampling of sediment and water of Lake Ontario near Toronto, Canada, found that a considerable portion of microplastic fragments had a twisted, curved character, and others resembled molten plastic that had flowed and hardened [Fig. 2(b)]. Anecdotal discussions have indicated that such plastic particles are likely ‘trimmings’ or ‘flash’ from manufacturing and moulding processes from the trimming of seams (twisted plastic) and melted plastic that escapes the moulds during processing. Fragments with these characteristics can be referred to as ‘commercial-activity-related fragments’. Further investigation could lead to considering other classifications within the broader fragment category, perhaps by establishing a source reference library. I look forward to the contributions from across the disciplines involved in microplastics in establishing such a resource.

The use of more source-specific classifications within microplastic particle categories will help focus management activities and enhance our ability to monitor the effectiveness of those
activities when implemented. The establishment of separate categories for spherical and irregular microbeads will allow for better tracking of changes in abundance, which is likely to occur given specific actions like companies voluntarily removing plastic microbeads from products and the impending bans on their use in personal-care products. Classifying fragments predominantly from litter/debris separately from commercial-activity-derived fragments could result in altering the emphasis of management activities. For example, in a water sample from Lake Ontario near Toronto, Canada, 73% of the particles collected were fragments [Fig. 3(a)]. Incorporating commercial-activity-based fragments into the profile indicates that such sources can be dominant, with 54% of the total number of particles allocated to this classification, while litter/debris fragments contributed 18% of the total [Fig. 3(b)]. These findings are consistent with abundances found in sediment in the same area, and with the density of plastics-related businesses located in the watersheds of the region.10 In this case, such a classification indicates that different management activities would be required to address such sources (e.g., education and outreach to appropriate facilities or commercial sectors) relative to those aimed at consumer-based litter/debris (recycling).

There are, however, challenges to this approach. While methodological enhancements move to more rapid analyses for abundance measurements and polymer identification for monitoring and exposure assessment, the taxonomic approach requires more scrutiny of the morphology of the particles and will remain time-consuming. Chemical-based scanning techniques (FTIR and Raman spectroscopy) aim to reduce error introduced by human judgement in identifying particles as plastic. However, the taxonomic approach is inherently reliant on visual identification and human judgment. This subjectivity will result in some degree of classification error where, for example, irregular microbeads may be considered fragments due to their shape (Fig. 1) and some abraded litter/debris fragments could be judged to resemble those from ‘commercial sources’ and vice versa. Standardized morphological keys and descriptions, practice and training, and selective validation by chemical and enhanced microscopy techniques [FTIR, Raman and/or mass spectroscopy, scanning electron microscopy (SEM)] could help to reduce such error. The degree of error may still be acceptable for the intended application and for purposes of managing sources and tracking the success of reducing inputs.

Enhanced morphological techniques already play an important role in developing an understanding of microplastic fate and identifying particles in the environment. Examples include morphology determined by SEM providing an indication of how plastic particles age and degrade in the environment,11 fiber morphology enhanced using SEM to aid in the differentiation of synthetic fibers, anthropogenic fibers from natural materials, and those from biological organisms,9 and assessing the effects of a treatment process on the character of microplastics in sewage sludge.12
In Ontario, the government has acknowledged that there are a wide variety of sources of microplastics, and that several management strategies will be necessary to effectively reduce the amount of material entering the aquatic environment. The response of private-sector companies, non-governmental organizations, governments, and the general public to the plastic microbead issue indicates that there is willingness by all parties to address plastics in the environment. Initiatives such as enhanced re-use/recycling of waste materials by producers, and extending producer responsibilities are a couple of examples that will have benefit. I am confident that improved source apportionment and sampling, extraction, and characterization methods will enhance our knowledge of particular microplastic sources, allowing for stakeholder engagement across sectors to identify management strategies to reduce the occurrence of microplastics in the environment and to help protect ecosystem health.

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References