Microplastics in the environment: much ado about nothing? A debate

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Abstract

This manuscript documents a debate between the two authors on the issue of microplastics in the environment. It was sparked by a recent viewpoint article published by G. A. Burton in Environmental Science and Technology (http://doi.org/10.1021/acs.est.7b05463) and started as a Twitter debate. To expand, we decided to continue our conversation publishing 1000-word texts on peerJ and responding to each other in roughly two-week intervals.

Currently, the text contains the following:

1) An introduction, which sets the scene for the article

2) Martin's kick-off statement “Soul-searching on microplastics: Lost in translation, prioritization and communication?”, dated Feb. 27, 2018

3) Thomas' opening statement “A genuine research topic, but let’s avoid hyperboles”, dated March 18, 2018

4) Martin’s rebuttal “Moving forward: What are the risks of microplastics?”, dated April 18, 2018

Introduction

The idea for this slightly unusual article was born from a debate on Twitter. Both of us read the recent viewpoint article by G. Allen Burton, the editor-in-chief of “*Environmental Toxicology and Chemistry*” (Burton, 2017). In his opinion piece, Burton argues that exposures to microplastics are too low, so they do not represent an environmental risk. As a result, Burton concludes that their investigation could be safely abandoned. We both found Alan’s text thought provoking but came to different conclusions.

Basically, Martin perceived Burton’s viewpoint as “too simplistic”, while Thomas agreed with Burton that the risk of microplastics is overstated. Martin pointed out that our lack of

knowledge on the environmental impacts of microplastics warrants further investigation. Thomas argued that – keeping limited resources in mind – other environmental risks are more pressing than microplastics and deserve our attention. We both agreed that our disciplines are not really good at prioritizing risks and that scientists are too often hunting for the "next big thing" are a result of perverse incentives in academia. The complete Twitter conversation is provided in the supporting information (SI).

However, Twitter quickly proved to be too clumsy for a decent debate. So, we decided to continue the conversation in a format that is more suitable for an exchange of real arguments and viewpoints. This paper documents our conversation, statement by statement.

Our setup for the debate was as follows:

1) An initial statement from Martin.
2) Comment/rebuttal from Thomas.
3) Re-rebuttal by Martin.
4) Re-rebuttal by Thomas.
5) Final statement by Martin and Thomas, written independently and in parallel by each author.

Each statement is allowed a maximum length of 1000 words and 10 references. A figure counts as 200 words. We will amend/have amended this debate article successively with each new piece of text, making use of the fact that a preprint can be updated. The final comments will be written in parallel by both authors, on the basis of the first four statements.

This paper is, therefore, certainly not a classical peer-reviewed scientific article or review paper. Instead, it is a debate that reflects our individual perspectives, value judgments and scientific backgrounds. The text is initially published as a PeerJ preprint, which allows readers to post comments. We welcome any and all feedback and hope our conversation adds to a broader discourse on the environmental relevance of microplastics.

Soul-searching on microplastics: Lost in translation, prioritization and communication?

Martin Wagner

By taking an extreme stance (microplastics = no risk), Burton's polemic (Burton, 2017) forced me to reflect on my position as well as the underlying arguments and motivations. Sometimes, it takes a devil's advocate to move the debate forward and I am grateful to Burton for playing that role. However, the scientific partisanship regarding microplastics is irritating: In one corner, we have Burton's "null risk" camp directly opposing the "all risk" camp (Rochman et al., 2015) in the other. Holding extreme positions on either end of the spectrum is valid when backed by strong arguments. I find these missing on both sides (see SI). For the sake of this discussion, I will, however, focus on less obvious aspects I encountered during my soul-searching.

Lost in translation?

At times, one can get frustrated with sensationalist media reports on (micro)plastics, I give Burton that. The question now is: Does the sensationalism originate in exaggerated scientific publications, as he claims? I believe – for most cases – this is not so. The majority of publications introduce plastic pollution as global problem referring to the massive amounts humankind produces and emits. This is something we all can agree upon. They continue by highlighting its potential biological or ecological impacts leading to the specific research question. Although it may become boring reading this over and over again, nothing is wrong with it as long as we take it for what it is: A hypothesis.

Misinterpreting hypotheses as facts is a translational problem we often encounter in risk communication. Journalists sometimes fall for that fallacy ("microplastics may be toxic" is received as "microplastics are toxic"). Burton does the same when he accuses "fellow scientists" of exaggeration. To test whether this is such misinterpretation, we analyzed the content of microplastics publications in "high-impact" journals. We found most narratives on their impacts to be associated with subjunctive phrasing, i.e., these indeed are hypotheses (Kramm & Völker, unpublished data). Nonetheless, our community can certainly improve in formulating explicit and specific hypotheses to avoid ambiguity. This is something we as authors, reviewers and editors clearly need to work on.

We encounter another translational issue: As toxicologists, we have internalized a very specific risk conception, namely that risk = exposure × hazard. Other disciplines involved in

microplastics research may apply different concepts. For instance, marine biologists often consider microplastics a risk because they are ubiquitous, persistent and ingested by biota. From this perspective, it is imperative to raise the red flag. Is their risk paradigm less valid than ours? I am not so sure anymore, especially since we have little means to assess the long-term ecological consequences of (micro)plastics. We might experience "domain inequality" in the sense that one pieces of disciplinary information cannot be understood without completely different expertise (How to avoid glib interdisciplinarity, 2017). To solve the wicked problem of plastic pollution, we need to work interdisciplinary. To work interdisciplinary, we need to overcome this inequality and develop a mutual risk understanding.

Attention deficit syndrome?

Colleagues often banter about the massive attention microplastics receive, both, inside and outside academia. Rather than culturing professional jealousy, they may worry that the "microplastics hype" withdraws attention and consequently resources from more relevant issues. Although I am not aware that microplastics drain for instance global warming science, this concern reveals a fundamental issue: A system in which researchers vigorously compete for resources produces a range perverse incentives (Edwards & Roy, 2017). One of the unintended results is that such system rewards those that exaggerate environmental risks. This can even turn into scientific fraud as the recent #perchgate episode painfully demonstrated (Enserink, 2017).

In that sense, we have built a system in which environmental issues complete against each other for attention. This conflict is amplified when it enters the 24/7 news cycle, which favors doomsday communication. Today, microplastics may have won the competition. Tomorrow, there will be another champion (glyphosate, NO_x etc.). Is this an academic problem? It becomes one once decision makers allocate research dollars according to news coverage. However, we cannot blame others. The root of the problem is rather that the community has no adequate tools to prioritize environmental issues and reach consensus on their relevance. This may be due to the skepticism inherent in the scientific endeavor, disciplinary echo chambers or academic inertia.

In any case, our inability to prioritize diminishes the impact of our science on societies and political decisions. If science cannot decide, societies will decide without science; as the microplastics case illustrates (Kramm et al., 2018). If we want our voices to be heard, we should learn from global warming science and instate an Intergovernmental Panel on Chemical Pollution (Scheringer, 2007) or on Plastic Pollution (IPPP) for that matter. Such bodies could identify priority pollutants, assess the state of the science and propose research agendas from a multidisciplinary perspective. This would foster building scientific consensus and communicating environmental issues.

Communicating the right thing in the wrong way?

The aspect I most struggle with is Burton's claim that science has "adversely influenced" political decisions on microplastics. To me, it is obvious that the way we currently produce and use plastics is not only unsustainable but plainly silly. The public debate on microplastics helped exposing the many shortcomings of our linear economy, raised public awareness and generated positive momentum for change. The European Union's Strategy for Plastics in a Circular Economy is one example of this (European Commission, 2018).

Even if the environmental risks of microplastics were low, would we do wrong in promoting a more sustainable use of plastic materials? I do not think so. However, I believe the current narrative we use to legitimize such change is inadequate (see Tab. S2). It mainly builds on the hypothesized risks of microplastics to wildlife and humans health and often ignores context and uncertainty (Rist et al., 2018). More importantly, a narrative based solely on toxicity neglects other important aspects regarding the societal and economic implications. I believe, we need a new narrative on (micro)plastic pollution that covers all these factors.

A genuine research topic, but let's avoid hyperboles

Thomas Backhaus

It might be useful to frame the topic(s) at hand. There are at least three separate issues, nested into one another:

1) Plastic pollution.
2) Pollution with microplastics.
3) Pollution with microbeads, i.e. deliberately produced microplastic, used in down-the-drain personal care products (PCPs).

Plastic pollution is quite obviously a critical environmental problem. For me it falls squarely into the category "so obvious that we need to work on solutions immediately and must not wait for more scientific research", similar to climate change.

However, microplastic particles (and PCP microbeads in particular) are only small subsets of the bigger problem. Microplastic particles occur globally and are of course a genuine research topic for environmental sciences, including toxicology, ecotoxicology and risk analysis. But, as Martin pointed out, we need to be careful about the conclusions we draw, how we move research forward and especially how we communicate the issue to the public and policy makers.

Environmental risks from microplastics?

I am squarely with Burton (2017) here. So far, I have not seen evidence that microplastics cause environmental risks, if we define "risk" as a situation where the ratio of exposure and hazard approaches or even exceeds 1. Empirical data and modeling efforts show that microplastic and microbead concentrations are very low in relation to their toxicity to humans and environmental organisms. This seems to hold true not only for direct particle effects but also for effects of microplastic-associated chemicals.

But maybe I am missing important studies that show otherwise?

No risk being identified at the moment of course does not allow us to conclude that there also will be no risk in the future. Given that in the environment billions of macroplastic items currently disintegrate slowly into microplastic, and in view of the anticipated enormous increase in the production of single use plastics such as packaging (The Guardian, 2017), we will certainly see a massive increase of microplastic pollution in the near future.

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Ways forward

The (eco)toxicological characterization of every conceivable future exposure scenario is impossible, and so is proving the absence of risk. We therefore need to gain a better and more systematic understanding under which circumstances and at which locations environmental risks and risks for human health might develop. We need more and better studies that systematically scan the horizon, contextualize the issues at hand, and finally develop scenarios that guide research and provide policy options.

Especially research on the (eco)toxicology of microplastics seems mainly exploratory at the moment. It is too rarely hypothesis driven and confirmatory (see Backhaus & Trier (2015) for a discussion of both research types and their complementary roles in chemical risk assessment and management). We should acknowledge falsifiability as one of the basic principles of scientific inquiry. I would therefore like to suggest the following null hypothesis: *microplastic particles are (eco)toxicologically equivalent to natural organic particles*. Only if we can disprove this initial null hypothesis should we argue that microplastics potentially cause environmental pollution that warrants action.

Working towards falsifying this hypothesis has hands-down consequences for the design of ecotoxicological studies. In particular, we have to acknowledge the fact that the natural environment is not particle-free and never has been. Organisms therefore adapt quite well to particles. In an (eco)toxicological study, microplastic-exposed samples should therefore not be compared to artificially particle-free controls, but to controls that contain realistic amounts of natural particles.

Microplastics are a case in point that ecotoxicology needs to evolve and become more environmentally realistic, embracing the concept of "stress ecology" (van Straalen, 2003). We need to focus more on ecologically relevant endpoints, and on the role of (micro)plastic in the context of ecological processes and other stressors.

Hyperbolic statements have real-world consequences

Environmental research does not happen in a political vacuum. It provides the basis for environmental policy-making, and it shapes public risk perception. Scientific papers provide implicit or explicit policy advice. I wonder how grossly hyperbolic statements such as "*Microplastic contamination of the oceans is one of the world's most pressing environmental concerns*" (Hurley et al., 2018) sound to somebody who works in areas devastated by oil production (say, the gulf of Mexico, the Prince William sound, the Congo basin), or who studies the cooked and bleached corals of the Great Barrier Reef.

It is hardly surprising that such statements from the peer-reviewed scientific literature (from a *Nature* journal even!) are taken up in new environmental legislation. For example, the current draft of the EU Directive on the quality of water intended for human consumption reads in its Article 8 on "Hazard assessment of bodies of water": *"Microplastics are of particular concern due to the negative effects on marine and freshwater environments, aquatic life, biodiversity, and possibly to human health since their small size*

facilitates uptake and bioaccumulation by organisms, or toxic effects from the complex mixture of chemicals these particles consist of." (EU Commission, 2017). Where is the evidence that supports such strong statements? At least I could not find any study that demonstrates negative effects of microplastics on, say, biodiversity.

Just like everybody else, I struggle to rank environmental problems. We simply want to tackle them all. But unfortunately, environmental management operates under severe resource restraints and we live in a world with an extremely limited supply of political will and societal motivation to act on environmental issues. So we have to pick our battles carefully. As the old saying goes: "If they can get you asking the wrong questions, they don't have to worry about answers" (Pynchon, 1937).

We have to consider the opportunity costs of hyperbolic statements and the political actions they might trigger: widespread monitoring of microplastics in our water supply, for example, will certainly redirect scarce resources away from monitoring more relevant pollutants. Flagging microplastics as "the most pressing environmental concern" of our times simply trivializes truly critical environmental problems, which are in ample supply.

Moving forward: What are the risks of microplastics?

Martin Wagner

There are many aspects in Thomas' previous statement I fully subscribe to. Importantly, the lack of systematic, conceptual and hypothesis-driven research in environmental toxicology is a serious issue, which expands beyond microplastics. While I understand that these shortcomings originate in the history of our discipline, this is something we as a community need to address. This is especially so if we want to evolve from a science tackling very applied problems (e.g., chemical risk assessment) into one addressing more basic questions (e.g., stress biology, to pick up Thomas' idea). I use the "if" on purpose here because not everybody in the community may share the need for evolving that way.

Take the recent microplastics debate: We are applying a risk framework or conception designed for a very specific application (regulatory decision on the safety of one chemical) to a pretty basic problem (global plastics pollution). To me, this implies that we have decided to frame the plastics problem in a very applied sense, as if we wanted to regulate one compound before it enters the market. As explained elsewhere, I disagree with framing Anthropocene issues in such a narrow way because it neglects the highly interconnected ecological, economic and societal risks (Kramm et al., 2018).

Leaving economics and societies aside for a minute, I believe that we have hit a dead end with our reductionist approach to environmental risks. While the classical risk assessment approach has worked reasonably well for chemicals we now call legacy pollutants, the amount and diversity of synthetic chemicals has tremendously increased since then (Bernhardt et al., 2017). Accordingly, we are not dealing with the "dirty dozen" anymore but with the unknown thousands. In the light of continuing biodiversity loss and assuming chemical pollution is one of its drivers, it is fair to assume that our classical risk framework is insufficiently protective. The reason is simple: It is not built to address the ecological consequences of long-term exposures to low concentrations of chemical mixtures.

While this problem has been acknowledged by many, I believe we still underestimate the extent by which the traditional PEC/PNEC paradigm[1] has shaped our risk perception and, thus, our research. Taking this one step further, insisting on a simplistic, numerical and almost bureaucratic risk paradigm may be exactly what is preventing us from moving forward, from exploring the idea that risk depends on (ecological) context, from making ecotoxicology more "environmentally realistic". Again, the microplastics discourse provides the opportunity to critically reflect on our traditional risk paradigm (Kramm et al., 2018).

[1] PEC = predicted environmental concentration, PNEC = predicted no effect concentration

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My fundamental critique of the PEC/PNEC paradigm notwithstanding, let us view the microplastics problem through that lens: Ignoring information scarcity, methodological limitations and other uncertainties, we can do the risk assessment exercise for freshwater ecosystems. I use this as a case because toxicological data from "standard" testing are more readily available than for the marine species. Last time I searched ISI Web of Science,[2] 27 peer-reviewed studies were available, including twelve studies actual toxicity studies.

The study reporting the lowest microplastics concentration inducing a significant effect is the one by Wen et al. (2018). Without going into detail, discus fish were exposed to 200 µg polyethylene beads L^{-1} over 30 d. This significantly reduced their predatory performance. Accordingly, the lowest so far reported LOEC[3] (no EC_{10} available) is 200 µg L^{-1} or 871 beads L^{-1} (recalculated). Other than in the usual hazard assessment, I did not evaluate the quality of the study to avoid bias.

Assuming a worst-case scenario, I looked for the highest reported microplastics concentration in rivers and lakes. For this, I used publications published until 2017 retrieved from ISI Web of Science.[4] I screened the results to extract 14 studies reporting actual concentrations in inland waters. Here, the study by Su et al. (2016) conducted on Taihu Lake, China provides the highest so far reported concentrations. Using grab sampling, the authors report a maximum concentration of 25.8 microplastics L^{-1} (PEC). Again, I did not evaluate the study's quality.

If we now apply a low assessment factor of 10 (assuming we had high confidence in the available data), we derive a PNEC for fish of 87 microplastics L^{-1}. The risk quotient resulting from the PEC/PNEC ratio is 0.3. Although the margin of safety for the risk quotient to reach 1 (= risk) is small, we can conclude that at the current date (or better based on current knowledge), microplastics pose no environmental risk according to the traditional approach.

What about the future? We can perform a prospective risk assessment assuming that no lower PNEC will be established but the production volume of plastics will increase. Using a business-as-usual scenario (i.e., no mitigation measures), we can assume increasing production volumes will directly translate to increasing environmental concentrations of microplastics (i.e., PECs). Using the data by Geyer et al. (2017), the mean annual growth rate of plastics production is 7.48% (since 1950) or more conservatively 3.85% (since 2000). Projecting PEC/PNEC ratios (Fig. S1) for these two growth rates results in risk quotients exceeding 1 in the years 2033 (7.48%) or 2048 (3.85%). This leaves us 15–30 years until microplastics would pose an environmental risk according to our traditional assessment framework.

[2] 27.03.18, search terms 'microplastic* AND freshwater AND toxic*'
[3] lowest observed effect concentration
[4] search terms 'microplastic* AND lake* OR river*' and alternatively 'microplastic* AND freshwater'

To me, this back-of-an-envelope exercise poses more questions than it provides answers. Provided we insist on framing the risk of microplastics based on PEC/PNEC ratios, we need to ask ourselves:

- How much knowledge do we need to conduct such an assessment?
- How much (un)certainty do we assign to such an assessment?
- Can we apply the approach for the heterogeneous group of microplastics?
- How do we factor in other agents of global change?
- Should we apply the same approach to macroplastics?
- Should we apply the same approach to other Anthropocene issues as well?
- Is the approach adequate for assessing complex environmental issues?
- Is the approach sufficiently protective?
- Do we postpone mitigation actions until the PEC/PNEC ratio reaches 1?
- What will be the costs of inaction?

Conflict of interest statement (Martin Wagner). I am not financially or otherwise associated with any organization or entity that would gain profit from this work.

Conflict of interest statement (Thomas Backhaus). I am an Academic Editor for PeerJ. I am also a board member of the Food Packaging Forum (FPF) and the International Panel on Chemical Pollution (IPCP), two NGOs that work on the issue of plastic packaging and chemical pollution in general. I do not receive any personal benefits from this work, financial or otherwise.

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