Environmental impact assessment of plastics and associated chemicals to support the transition to a non-toxic environment for humans and wildlife

Background/Motivation: Plastics are everywhere: Widespread contamination with macro-, micro- and nanoplastics represents a global threat, and their accumulation in the terrestrial, aquatic and marine environment is poorly reversible. Plastics are omnipresent in all environmental compartments, our drinking water and food, where they adversely impact humans and wildlife. Particles are directly taken up by diverse species, including humans, eliciting direct effects such as inflammation. They also act as carriers to transport chemicals into living organisms with related indirect adverse effects. Plastics are hypothesized to aggravate biodiversity loss and climate change through their impact on threatened species that encounter plastics, as well as plastic accumulation in soil and sediment impacting biogeochemical cycles. In this, plastics contribute substantially to the triple planetary crisis of pollution, biodiversity loss and climate change. Following the precautionary principle that seeks to protect the environment and humans from the potential for harm, and in accordance with the United Nations Sustainable Development Goals (SDGs, which specifically address plastics, *e.g.*, in SDG14 "Life Below Water"), there is broad agreement that multiple measures need to be taken urgently to largely cut plastics emissions to the environment. These measures include a transition towards circularity involving improved waste and wastewater handling, effective plastic recycling strategies reducing production of new plastics while keeping chemicals therein at acceptable levels, and a switch to new, fewer, better characterized and less harmful polymers and additives. The ongoing discussions by the United Nations Environment Programme (UNEP) Intergovernmental Negotiating Committee (INC) on Plastic Pollution to develop an international legally binding instrument on plastic pollution further underline the importance of solid science to support such transition measures.

Unique selling points:

We follow a One Health perspective covering exposure and health consequences for ecosystems and humans. We address the complexity of the (chemical) exposome, i.e., the totality of plastics and plastic-associated chemicals. We apply chemical and biochemical analytics, perform dedicated experiments and monitoring and develop models to understand the transport and fate of plastics and plastic-associated chemicals, with the final goal to contribute to their risk management.

At UFZ, multiple research lines address diverse elements of the environmental impact assessment of pollution by plastics and tire wear particles to ***(a)*** quantitatively assess and more accurately describe and model exposure, transport and fate in and across diverse ecosystems from land via rivers to the sea, and identify hot spots for accumulation, ***(b)*** identify problematic materials, sizes, shapes, concentrations and properties, ***(c)*** assess mixtures of chemical additives and pollutants sorbed to plastics, ***(d)*** characterize effects on aquatic organisms, human cells and soil carbon stocks, ***(e)*** track the plastic particles' environmental weathering and its impact on transport and fate, ***(f)*** point towards solutions that involve plastic degradation and re- or upcycling, or materials that may be more sustainable such as "bioplastics", and ***(g)*** communicate our findings to the scientific community, policy-makers and the general public to foster broad willingness for change.

See also www.ufz.de/microplastics for a summary of our expertise.

Mission/Approach: We strive to provide tools and knowledge to characterize environmental contamination of micro-/nanoplastics and associated chemicals as a profound basis to provide recommendations for their risk management, e.g., via the identification of compounds that need specific action, the identification of hot spots, etc. We constitute a strong collaborative scientific community, internally and externally, interlinked with the most relevant stakeholders, providing solid scientific knowledge to support policy-makers and regulators as these stakeholders facilitate the legal transition to a non-toxic environment for humans and wildlife.

Ambassadors: Annika Jahnke, Dana Kühnel (**RU3**); Involved scientists (postdoctoral researchers and senior scientists): Evgenia Blagodatskaya, Nadiia Yamborko (**RU1**), Jan Fleckenstein, Christian Schmidt, Katrin Wendt-Potthoff (**RU2**), Alexander Böhme, Eric Carmona Martínez, Martin Krauss, Stefan Lips, Dušan Materić, Guyu Peng, Mara Römerscheid, Elisa Rojo-Nieto, Mechthild Schmitt-Jansen, Kristin Schubert, Nadin Ulrich, Martin von Bergen, Daniel Zahn, Ana Zenclussen (**RU3**), Christian Eberlein, Hermann Heipieper, Thomas Maskow, Katrin Mackenzie, Dietmar Schlosser, Matthias Schmidt, Hryhoriy Stryhanyuk (**RU4**), Rohini Kumar, Lennart Schüler (**RU5**), Anran Luo (**RU6**)

Figure 1. Graphical abstract of the microplastics competence cluster at UFZ.

Results/Products: Our primary research outcomes are published in impactful publications, describing the global threat from plastic pollution based on areas of irreversible accumulation https://doi.org/10.1126/science.abg5433 (topics ***b,d,e,f,g***, times cited: 511), identifying weathering plastics as a planetary boundary threat https://doi.org/10.1021/acs.est.1c01512 (***a,b,c,d,e,*** 92), elucidating an important biogeochemical mechanism that makes buoyant microplastics sink https://doi.org/10.1016/j.watres.2020.116582 (***a,e,*** 33), characterizing transport and fate of microplastics in riverbed/hyporheic sediments https://doi.org/10.1016/j.watres.2023.120349 (***a,b,*** 0), assessing implications of global transport of nanoplastics based on data from Northern and Southern polar ice https://doi.org/10.1016/j.envres.2022.112741 (***a,b,*** 51), characterizing global riverine plastics emissions into the ocean https://doi.org/10.1126/sciadv.aaz5803 (***a,*** 296), shedding light on biochemical mechanisms involved in bacterial degradation of polyurethane compounds https://doi.org/10.1038/s41598-022-06558-0 (***f,*** 9), summarizing current knowledge on human exposure to nano- and microplastics from relevant sources https://doi.org./10.1016/j.impact.2022.100441 (***a,b,g,*** 9), illustrating the importance of plastic-attached dissolved organic matter for bacterial colonization https://doi.org/10.1021/acs.est.0c07875 (***b,c,d,*** 24), elucidating adverse effects of bisphenol A and substitutes on human adipocytes https://doi.org/10.1016/j.envint.2021.106730 (***d***, 17), characterizing the occurrence and fate of the key tire-related chemicals 6-PPD and 6-PPDQ in snowmelt https://doi.org/10.1016/j.watres.2022.118122 (***c***, 50) and revealing up to 45% reduction in soil biodiversity as a result of plastic contamination https://doi.org/10.1186/s12302-021-00528-5 (***d,f***, 19).

In terms of our network, within the Helmholtz Association of German Research Centres (HGF) we actively collaborate with scientists at the Alfred Wegener Institute for Polar and Marine Research (AWI), Helmholtz-Zentrum Hereon and GEOMAR Helmholtz Centre for Ocean Research Kiel. Other key universities, research institutions and regulatory agencies within our network are: (1) **DE**: University of Leipzig, University of Bayreuth, University of Münster, Technical University of Munich, Fraunhofer IKTS, Fraunhofer IME, Leibniz Institute for Trophospheric Research (TROPOS), Leibniz Institute for Baltic Sea Research (IOW), Senckenberg am Meer, Bundesanstalt für Materialforschung und -prüfung (BAM), German Federal Institute of Risk Assessment (BfR); (2) **EU**: University of Ljubljana, Stockholm University, Wageningen University and Research, Utrecht University, DELTARES, SINTEF, Norwegian Geotechnical Institute (NGI), Mediterranean Institute of Oceanography (MIO), Norwegian Institute for Air Research (NILU), Spanish National Research Council (CSIC); (3) **non-EU**: University of Canterbury New Zealand, the Fluminense Federal University Brazil, Kunming Institute of Botany China, UNEP, Food and Agriculture Organization (FAO) of the United Nations, International Atomic Energy Agency (IAEA), Malaysian Nuclear Agency, Environment and Life Sciences Research Center Kuwait, Biotechnology and Nuclear Agriculture Research Institute Ghana.

We are widely involved in national (BMBF: InnoMatLife 2019-22, ***b,d,*** Andromeda 2019-21), European (EU: PlasticsFatE, 2021-25, ***d,e,g***, PlasticHeal 2021-25) and international (MicroPLUS 2023–27 FAO/IAEA, ***a,b,d,e,f,g***) consortia. Recent projects coordinated at UFZ are: MICRO-FATE (BMBF 2019-21,

a,b,c,d,e,g), MikroPlaTaS (BMBF 2018-21, *a,b,d,g,e*) and P-LEACH (HGF 2022-24, *c,d,e,g*). Furthermore, we have contributed or contribute to the following relevant projects: Collaborative Research Centre 1357 Microplastics (DFG SFB 1357, 2019-26, *a*), FINEST (HGF Sustainability Challenge, 2022-27, *f*), PARC 5.2.1/Metabolic Disruption (EU, 2022-29, *d*) and Collaborative Research Centre 1052 – Obesity Mechanisms (DFG, 2021-24). **Taken together, our related third-party funding totals at least 4.079 k€ (plus 405 k€ for P-LEACH and 347 k€ for tenders) from 2021 onwards (UFZ contribution only).** In addition, a new 6-year Emmy Noether grant (Kristin Schubert) is dedicated to the endocrine disruption of plastic-associated chemicals (ca. 2.000 k€).

Outreach/Impact: Our website is: www.ufz.de/microplastics. In addition to numerous (partly invited) presentations at scientific conferences (*e.g.*, MICRO, SETAC, EGU, EUROTOX), we have been invited to high-level discussions including the International Symposium on Managing Land and Water for Climate-Smart Agriculture at the IAEA's Headquarters in Vienna, Austria. We are actively in contact with the media (print, podcasts, websites, radio, TV) and frequently respond to related requests (interviews, consulting for TV programmes). We prepared the touring exhibition "Wissenschaft macht Schule" (https://www.ufz.de/export/data/2/260470_flyer._pdf) and further education materials and factsheets (*e.g.*, https://bmbf-plastik.de/en/_publication/are-microplastics-harmful) as well as the UNEP guidelines on freshwater plastics monitoring and assessment (https://www.unep.org/resources/report/monitoring-plastics-rivers-and-lakes-guidelines-harmonization-methodologies). We contributed exhibits and knowledge to the container-based exhibition OceanPlasticsLab (https://www.deutsche-meeresforschung.de/en/ausstellung/_2074/). We have created a research comic outlining a selection of outcomes from our project WEATHER-MIC (https://doi.org/10.13140/RG.2.2.20455.29603). We are active at diverse Researchers' Nights, with the UFZ students' lab and within the UFZ Summer Camps for kids between 7 and 12, amongst others.

With regards to impact, we contribute to regulatory activities such as 'Assessing the Fate, and Environmental Impact of Plastics in Soil and Crop Ecosystems Using Isotopic Techniques' coordinated by FAO and IAEA. Furthermore, we are members of the international expert group "Scientists' Coalition for an Effective Plastics Treaty" (SciCoa, https://ikhapp.org/scientistscoalition), in particular working group 3 on polymers and chemicals, and contribute with overviews, summaries and interpretations of scientific knowledge to decision-makers and the public involved in the negotiations towards a global agreement to end plastic pollution, in preparation of the UNEP INC meetings.

Our research supports the achievement of the goals of the EU Green Deal and the Zero Pollution Action Plan. It also aligns with the UN SDGs, several of which relate to plastic contamination, such as #3 "Good health and well-being" (*our work contributes to the elucidation of health effects of plastics contamination in water, air and soil, will support prevention*), #6 "Clean water and sanitation" (*we assess the role of contaminants in waste and drinking water, link to chemistry*), #12 "Responsible consumption and production" (*we work towards the characterisation of fresh water supply contamination*), #13 "Climate action" (*we assess the impact of plastic on biogeochemical cycles*) and #14 "Life below water" (*we support the characterization of microplastic transport and fate in the ocean*). Our research supports the implementation of the goals set out in the EU Strategy for Plastics in a circular economy, which is embedded in the EU Circular Economy action plan. One goal is the substantial reduction of microplastic formation and release. Here we contribute by improving the understanding on microplastics formation and identification of the adverse effects of associated chemicals. Results from elements ***b, c and d*** will support activities towards consideration of polymers under REACH, the EU chemical regulation. Currently, polymers are exempted from registration, but a discussion on potential criteria is underway to identify critical polymers for which registration will be mandatory. Our scientists contribute data and expertise to facilitate these decisions.

Next steps/Outlook: Following the validation of our multidisciplinary toolbox we aim to collaboratively apply the diverse expertise in larger contexts to characterize the impact of plastics and associated chemicals on the triple planetary crisis of pollution, biodiversity loss and climate change. As an example, a comprehensive sampling campaign in the Elbe River has just been finished. Sediment, water and biofilm samples were collected to characterize patterns and trends of micro-/nanoplastics and associated chemicals in the entire system from the source in the Czech Republic into the German Bight where the water masses are mixed with the North Sea water. Another example is the proposal for a UFZ PhD cohort covering plastics and associated chemicals (**RU3**), modeling (**RU5**) and policy interaction (**RU6**). We are eager to explore different options to maximize the impact of our broad joint expertise.