Under-researched and under-reported new findings in microplastic field.

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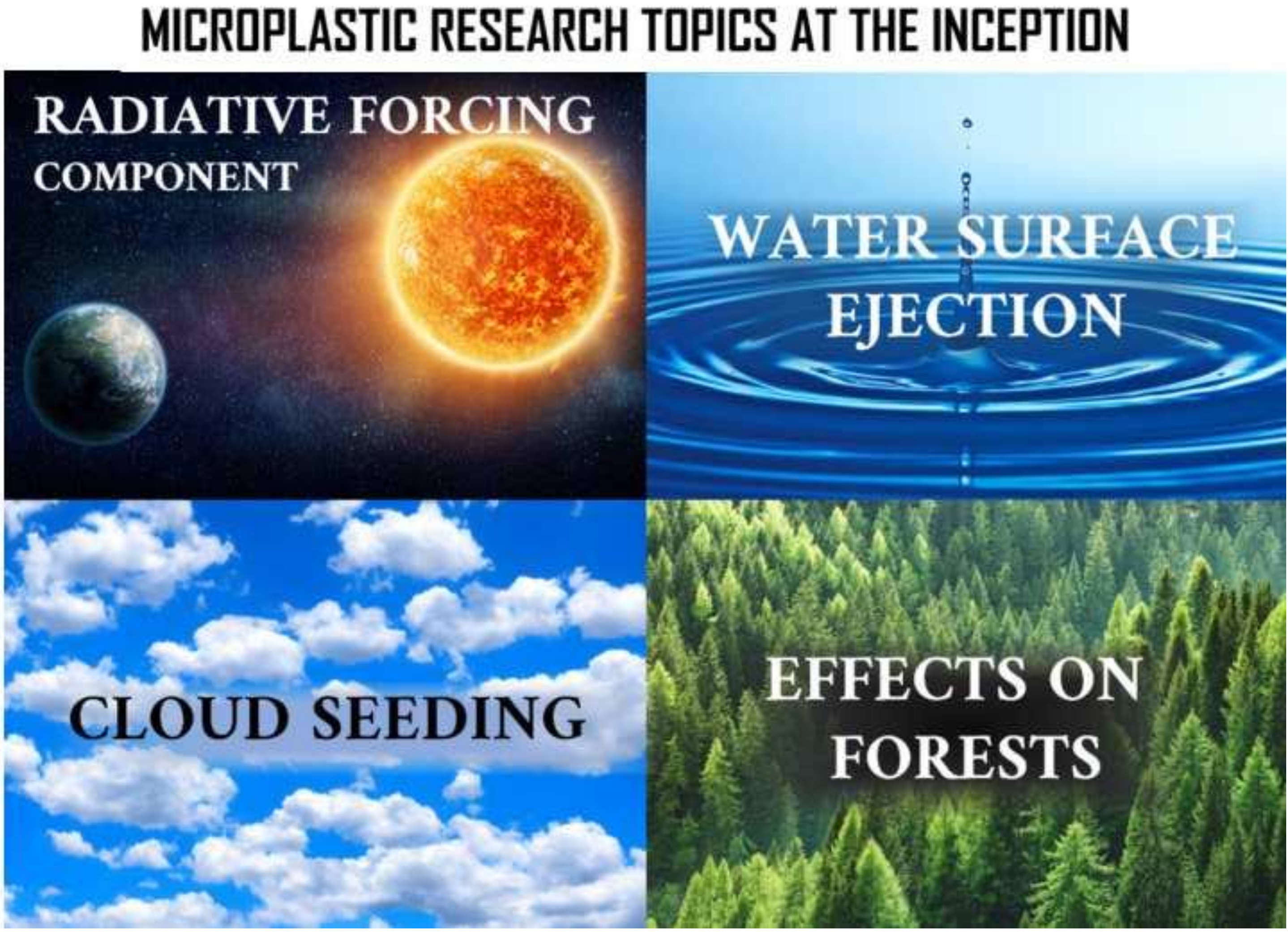
Abstract

After over 20 years of research on microplastic (MP) pollution, there are important areas of study which are still at the inception. In particular, between 2020-2023 new findings on MP have emerged, which open new sub-categories of MP research. These research areas include sea surface MP ejection, direct and indirect MP influence on climate and hydrological cycle, small and nano-sized MP analysis and the relationship between MP size and abundance. Not reported or barely mentioned in previous reviews, these globally-relevant findings are here highlighted and discussed with aim to promote their further research that will potentially result in new evidence of detrimental effects of MP pollution on the biosphere.



Nomenclature

MP (microplastics): all synthetic polymeric materials of any shape (fibers, fragments, films etc.) smaller than 5mm including the nanoplastics and small MP.

Small MP: specifically, MP smaller than 100 µm and larger than 1 µm.

NP (nanoplastics): specifically, MP smaller than 1 µm.

Introduction

Microplastics are a global environmental pollutant with a potential to cause significant damage to ecosystems, human health (Das, 2023; Bostan et al., 2023; Malafaia and Barcelo, 2023) and food productivity (Dainelli et al., 2023; Maity et al., 2022). There is also evidence that MP influence the Earth's climate and hydrological cycle (Wang et al., 2023; Revell et al., 2021; Evangeliou et al., 2020). The effect on climate can also be indirect, through impairment of life functions of photosynthesizing organisms, such as cyanobacteria (Zeng et al., 2023) and plants (Jia et al., 2023; Li et al., 2022). Owing to vehement increase in plastic production combined with inadequate management of waste (Lebreton and Andrady, 2019), MP are an increasingly potent danger to life on our planet and therefore require wide, quality scientific research and immediate enforcement of relevant environmental legislation. Plastic waste management and abatement legislation is key to avert MP crisis (Munhoz et al., 2023), but unfortunately it is in many countries non-existent (OECD, 2022) or was poorly designed and difficult to implement, such as the Marine Strategy Framework Directive (EC, 2020).

The difficulty in determining levels of MP in environmental or biological samples can be a level higher than for other pollutants such as heavy metals where typically a simple acid digestion is used to destroy matrix and solubilize the analyte. This is because the MP samples require special handling to preserve MP particles intact if quantitative (in number of MP) or descriptive information is needed (e.g. shape, degree of weathering, adsorbed chemicals, composition of the corona) (Huang et al., 2023). Once in the environment or within an organism, microplastics inevitably interact with molecules and undergo physicochemical changes both of which greatly modify MP behavior and toxicity (Cao et al., 2022), hence the importance of providing descriptive information of analyzed MP. The quantitative analysis of small MP, and in particular, NP in complex environmental samples is currently highly constrained and methods are limited to simulated samples in the simplest matrices such as distilled water (Pei et al., 2023; Dong et al., 2023). In these circumstances the limits of detection for MP leave out NP, for example in environmental snow, which is one of simplest matrices, the analysis was limited to 10 µm (Parolini et al., 2021), 30 µm (Ohno and Iizuka, 2023), 60 µm (Cabrera et al., 2022), 44 µm (Aves et al., 2022) or 11 µm (Bergmann et al., 2019). Even dedicated laboratories struggle to accurately quantify and determine MP of 300 µm-5 mm in size (Cadiou et al., 2020). Many studies may have over-estimated the scale of MP pollution, especially when a reliable verification method such as Raman Spectroscopy or Fourier Transform Infra-Red Spectrometry was not in use (Wesch et al., 2017; Kuklinski et al., 2019). Poor quality control is another important culprit resulting in overestimation, particularly for small MP and NP (Bai et al., 2023).

Despite over two decades of research and thousands of articles dedicated to MP, there are research areas that are still at inception. This is owed to the aforementioned analytical constraints, particularly associated with the size of NP and the complexity of MP interactions within the environment, as well as the fact that some findings are so recent that the scientific community has not yet been able to catch up with them. An example of such is the recent publication by Wang et al. (2023) and certainly similar research will stem from concepts materialized therein. On the other hand, there are numerous emulated literature reviews on ‘sources, distribution, environmental effects’ etc. that were evidently superficially composed with neglect of several important findings of 2020-2023 and which reiterated research that used to have shock value, i.e. about MP in human placenta and snow in the Alps. Conversely, in this article, research that were not accounted for in previous literature reviews are highlighted and prompted for further scientific exploration.

Underreported and underresearched findings in the discipline of MP pollution:

1. Size-abundance relationship

Currently, in the absence of methods that can accurately quantify MP down to the smallest NP in environmental samples, especially in the complex matrices such as biological tissues or soil, the well-reported analytical data and mathematics come in handy as a substitute until the desired technology is developed. Based on MP analyses from 127 articles, Leusch et al. (2023) calculated the estimated relationship between MP size and abundance in the environment, the MP property that was earlier suggested by Cozar et al. (2014). It is an increase by a factor of 1.3 to 7.9 per each order of magnitude in size decrease (Leusch et al., 2023). Beneath the limits of detection therefore there is a vast abundance of small MP and NP. For example, in Bergmann et al. (2019) 98% of all MP within 11µm-5mm size range were between 11µm and 100µm. With a typical marine sampling devices of <300µm permeability (Bohdan, 2022), the total number of MP that are not accounted for is very high. This leads to identifying an often-recurring mistake in articles that compare MP concentrations between studies with different limits of size detection without highlighting these limits. Such invalid comparison is misleading. Paradoxically, there are articles where the limit of detection was not reported at all (Leusch et al., 2023). It is therefore strictly important that whenever comparing the concentrations of MP between the studies, the MP size range should also be quoted.

2. Aerial transport from sea to land as a limb of MP cycle

Atmospheric concentrations of MP are more understudied than for other compartments and the implications of MP presence in the atmosphere are known only to a low certainty through preliminary studies. In Allen et al (2020) and in Trainic et al. (2020), the first evidences of MP transport from sea to land were reported. This was further experimentally corroborated by Lehmann et al (2021) who demonstrated how rain droplets cause the ejection of small MP from sea surface. Shaw et al. (2023) demonstrated the same, also calculating total global oceanogenic MP emissions. However, this was based on outdated and highly speculative data from pre-2013 and resulted in high uncertainty oceanogenic MP mass (0.02 - 7.4 Mt per annum). There are more recent and reliable datasets and estimates of MP abundance at global marine surface such as Isobe et al. (2021) or Bohdan (2022). Ferrero et al (2022) found correlation between airborne MP concentrations with abundance of MP at sea as well as with the concentration of sea spray, indicating their marine origin. González-Pleiter et al (2021) found that small MP originating from sea level can be aerially transmitted thousands of kilometers. Smaller MP are more likely to stay airborne for long durations, enabling their long - range transport, with estimated 17-37 days for MP particulate matter (PM) 2.5µm size class and about a day for PM 10µm size class (Evangeliou et al., 2020). These studies explain that abundance of MP in the atmosphere and their presence in the remotest locations can be attributed to a certain extent to the marine surface. More research is required to accurately quantify global atmospheric MP that come from marine surface (Brahney et al., 2021).

3. The effect of MP on radiative forcing and water cycle

Being present in the atmosphere and as a deposit on the surface, as any other type of aerosol, MP will affect radiative forcing, but the research on this topic is far from complete. It is therefore still unknown whether MP impact on climate is already significant. Lorian and Dagan (2023) linked anthropogenic aerosols to cooling effect. However, in cryosphere areas the MP could decrease the albedo and contribute to snow melting (Evangeliou et al., 2020). The value of direct radiative forcing, average for all types of MP, is unknown, although an attempt to calculate it is featured in Revell et al. (2021). As the authors themselves declare, it carries a high uncertainty due to lack of data on the effect of MP morphology, shape and color as well as due to almost non-existent data on vertical MP distribution in the atmosphere.

Microplastic behavior as cloud condensation nuclei and ice nucleating particles (CCN and INP) is one of the indirect ways MP aerosols influence radiative forcing and hydrological cycle. Based on particulate matter (PM) analysis, largely anthropogenic CCN concentrations (N_{CCN}) in cities range from 800 N_{CCN} cm^{-3} in Vienna, up to 8800 N_{CCN} cm^{-3} in Beijing for PM sizes of 10 to 900nm but mainly around 40nm (Rejano et al., 2021). It is unknown what percentage of that is NP. At present therefore, it is undetermined whether MP influence on N_{CCN} is negligible or significant due to lack of data on small MP and NP concentrations in the atmosphere. As previously described, currently analytical chemistry has difficulty to reliably quantify small MP and NP even in simple environmental matrices. The size-abundance correlation may be somewhat helpful to estimate atmospheric NP abundance at around 40nm using datasets of larger MP, but it is still unknown what part of this quantity will be hygroscopic. To date it is known that environmentally aged MP are more likely to act as CCN and INP (Wang et al., 2023; Evangeliou et al., 2020).

To date there is only one study which directly links MP to CCN. Wang et al. (2023) isolated 70 MP of 7-95µm in size from cloud water at mountain peaks and found 7 - 14 MP L^{-1} which were likely of sea origin. The total number of MP, including nanoplastic can therefore be much higher, considering size-abundance correlation estimated by Leusch et al. (2023), especially that smaller MP are more likely to become airborne (Evangeliou et al., 2020).

4. Environmental MP in plant tissues and tree toxicology.

The MP uptake by plants was demonstrated in laboratory conditions typically using marked MP in artificial samples (Jia et al., 2023; Zantis et al., 2023), even for the trees (Austen et al., 2022). Marked MP, for example by fluorescence dyes, are often used in order to enable their easy localization within the plant tissue (Austen et al. 2022). Due to technical constraints, there has been no research on the MP content in the actual environmental plant tissue samples. Such research would explain the properties and characteristics of aged environmental MP within the plants, toxicology, stress response, accumulation areas and potentially plant use for MP pollution biomonitoring and phytoremediation (Murazzi et al., 2022). The toxicology research of MP in respect to trees is almost non-existent and directed at agricultural species (Enyoh et al., 2020). Under increasing stresses on trees imparted by rise in spread of predominantly alien diseases and pests (Panzavolta et al., 2021), there is a particular urgency to assess potential MP role in weakening forest ecosystems and therefore the MP impact on the ability of global forests to continue to act as carbon sink, backbone of terrestrial ecosystems and providers of human amenities (Stier-Jarmer et al., 2021). Considering the crucial role of trees to sustain the life on the planet, research on MP toxicity and synergism with tree pest and disease in typical forest tree species such as oaks, birches, palms and pines is needed, covering subjects such as MP effects on seed germination, photosynthetic activity, chlorophyll content and biomass growth.

Final remarks

The MP research revealed the spread, circulation and accumulation of this pollutant throughout the biosphere and implications that the researchers a decade ago had not even conceived of. At present this research field advances so fast that the reviewers often fail to report highly important discoveries. These new and under-reported discoveries were here discussed with aim to inspire their further study. The growing evidence of detrimental MP effects will act as scientific pressure on law makers with the aim to design and enforce effective legislation to limit plastic pollution. One of the ways to achieve this may be classification of synthetic polymers as hazardous materials (Steensgaard et al., 2017).

From global environment point of view, there is currently a pressing need for developments in understanding of MP influence on climate, water cycle and forest health, as these research areas are at the inception. These potential influences could be inferred through modelling which requires excellent data reporting practice from studies on MP concentration or toxicology. Such practice includes provision of details on experimental design and results e.g. limits of detection, raw data, geographical coordinates of sampling. Poor data provision and insufficient methods description is an often-recurring cause for an article to be excepted from a model or a simulation (Leusch et al., 2023; Bohdan, 2022).

References

Allen, S., Allen, D., Moss, K., Le Roux, G., Phoenix, V. R., & Sonke, J. E. (2020). Examination of the ocean as a source for atmospheric microplastics. PLoS ONE, 15(5), 1–14. doi: 10.1371/journal.pone.0232746

Austen, K., MacLean, J., Balanzategui, D., & Hölker, F. (2022). Microplastic inclusion in birch tree roots. Science of the Total Environment, 808. doi: 10.1016/j.scitotenv.2021.152085

Aves, A. R., Revell, L. E., Gaw, S., Ruffell, H., Schuddeboom, A., Wotherspoon, N. E., … Mcdonald, A. J. (2022). First evidence of microplastics in Antarctic snow. Cryosphere, 16(6), 2127–2145. doi: 10.5194/tc-16-2127-2022

Bai, R., Fan, R., Xie, C., Liu, Q., Liu, Q., Yan, C., … He, W. (2023). Microplastics are overestimated due to poor quality control of reagents. Journal of Hazardous Materials, 459(April), 132068. doi: 10.1016/j.jhazmat.2023.132068

Bergmann, M., Mützel, S., Primpke, S., Tekman, M. B., Trachsel, J., & Gerdts, G. (2019). White and wonderful? Microplastics prevail in snow from the Alps to the Arctic. Science Advances, 5(8). doi: 10.1126/sciadv.aax1157

Bohdan, K. (2022). Estimating global marine surface microplastic abundance: systematic literature review. Science of The Total Environment, 832(April), 155064. doi: 10.1016/j.scitotenv.2022.155064

Bostan, N., Ilyas, N., Akhtar, N., Mehmood, S., Saman, R. U., Sayyed, R. Z., … Pandiaraj, S. (2023). Toxicity assessment of microplastic (MPs); a threat to the ecosystem. Environmental Research, 234(June), 116523. doi: 10.1016/j.envres.2023.116523

Brahney, J., Mahowald, N., Prank, M., Cornwell, G., Klimont, Z., Matsui, H., & Prather, K. A. (2021). Constraining the atmospheric limb of the plastic cycle. Proceedings of the National Academy of Sciences of the United States of America, 118(16), 1–10. doi: 10.1073/pnas.2020719118

Cabrera, Marcela & Moulatlet, G. & Valencia, Bryan & Conicelli, Bruno & Maisincho, Luis & Lucas-Solis, Oscar & AlbendÃ-n, Gemma & RodrÃ-guez-Barroso, M. & sakali, Ayda & Capparelli, Mariana. (2021). Microplastics in a tropical Andean Glacier: A transportation process across the Amazon basin?. Science of The Total Environment. 805. 10.1016/j.scitotenv.2021.150334.

Cadiou, J., Gerigny, O., Koren, Š., Zeri, C., Kaberi, H., Alomar, C., Panti, C., Fossi, M.C., Adamopoulou, A., Digka, N., Deudero, S., Concato, M., Carbonell, A., Baini, M., et al., 2020. Lessons learned from an intercalibration exercise on the quantification and charac- terisation of microplastic particles in sediment and water samples. Mar. Pollut. Bull. 154 (March), 111097. https://doi.org/10.1016/j.marpolbul.2020.111097

Cao, J., Yang, Q., Jiang, J., Dalu, T., Kadushkin, A., Singh, J., … Li, R. (2022). Coronas of micro/nano plastics: a key determinant in their risk assessments. Particle and Fibre Toxicology, 19(1), 1–25. doi: 10.1186/s12989-022-00492-9

Cózar, A., Echevarría, F., González-Gordillo, J. I., Irigoien, X., Úbeda, B., Hernández-León, S., … Duarte, C. M. (2014). Plastic debris in the open ocean. Proceedings of the National Academy of Sciences of the United States of America, 111(28), 10239–10244. doi: 10.1073/pnas.1314705111

Dainelli, M., Pignattelli, S., Bazihizina, N., Falsini, S., Papini, A., Baccelli, I., … Gonnelli, C. (2023). Can microplastics threaten plant productivity and fruit quality? Insights from Micro-Tom and Micro-PET/PVC. Science of the Total Environment, 895(June), 165119. doi: 10.1016/j.scitotenv.2023.165119

Das, A. (2023). The emerging role of microplastics in systemic toxicity: Involvement of reactive oxygen species (ROS). Science of the Total Environment, 895(June), 165076. doi: 10.1016/j.scitotenv.2023.165076

Dong, M., Luo, Z., Jiang, Q., Xing, X., Zhang, Q., & Sun, Y. (2020). The rapid increases in microplastics in urban lake sediments. Scientific Reports, 10(1), 1–10. doi: 10.1038/s41598-020-57933-8

EC (2020) Report on the implementation of the Marine Strategy Framework Directive. https://shorturl.at/fimyK

Enyoh, C. E., Shafea, L., Verla, A. W., Verla, E. N., Qingyue, W., Chowdhury, T., & Paredes, M. (2020). Microplastics Exposure Routes and Toxicity Studies to Ecosystems: An Overview. Environmental Analysis Health and Toxicology 35(1), 1–10.

Evangeliou, N., Grythe, H., Klimont, Z., Heyes, C., Eckhardt, S., Lopez-Aparicio, S., & Stohl, A. (2020). Atmospheric transport is a major pathway of microplastics to remote regions. Nature Communications, 11(1). doi: 10.1038/s41467-020-17201-9

Ferrero, L., Scibetta, L., Markuszewski, P., Mazurkiewicz, M., Drozdowska, V., Makuch, P., … Bolzacchini, E. (2022). Airborne and marine microplastics from an oceanographic survey at the Baltic Sea: An emerging role of air-sea interaction? Science of the Total Environment, 824. doi: 10.1016/j.scitotenv.2022.153709

González-Pleiter, M., Edo, C., Aguilera, Á., Viúdez-Moreiras, D., Pulido-Reyes, G., González-Toril, E., … Rosal, R. (2021). Occurrence and transport of microplastics sampled within and above the planetary boundary layer. Science of the Total Environment, 761. doi: 10.1016/j.scitotenv.2020.143213

Huang, Z., Hu, B., & Wang, H. (2023). Analytical methods for microplastics in the environment: a review. Environmental Chemistry Letters, 21(1), 383–401. doi: 10.1007/s10311-022-01525-7

Isobe, A., Azuma, T., Cordova, M.R., Cózar, A., Galgani, F., Hagita, R., Kanhai, L.D., Imai, K., Iwasaki, S., Kako, S., Kozlovskii, N., Lusher, A.L., Mason, S.A., Michida, Y., et al., 2021. A multilevel dataset of microplastic abundance in the world's upper ocean and the Lauren- tian Great Lakes. Microplast. Nanoplast. 1 (1), 1–14. https://doi.org/10.1186/s43591- 021-00013-z.

Jia, L., Liu, L., Zhang, Y., Fu, W., Liu, X., Wang, Q., … Huang, L. (2023). Microplastic stress in plants: effects on plant growth and their remediations. Frontiers in Plant Science, 14(August), 1–21. doi: 10.3389/fpls.2023.1226484

Kuklinski, P., Wicikowski, L., Koper, M., Grala, T., Leniec-Koper, H., Barasiński, M., Talar, M., Kamiński, I., Kibart, R., Małecki, W., 2019. Offshore surface waters of Antarctica are free of microplastics, as revealed by a circum-Antarctic study. Mar. Pollut. Bull. 149 (June), 110573. https://doi.org/10.1016/j.marpolbul.2019.110573

Li, J., Yu, S., Yu, Y., & Xu, M. (2022). Effects of Microplastics on Higher Plants: A Review. Bulletin of Environmental Contamination and Toxicology, 109(2), 241–265. doi: 10.1007/s00128-022-03566-8

Lebreton, L., & Andrady, A. (2019). Future scenarios of global plastic waste generation and disposal. Palgrave Communications, 5(1), 1–11. doi: 10.1057/s41599-018-0212-7

Lehmann, M., Oehlschlägel, L. M., Häusl, F. P., Held, A., & Gekle, S. (2021). Ejection of marine microplastics by raindrops: a computational and experimental study. Microplastics and Nanoplastics, 1(1), 1–20. doi: 10.1186/s43591-021-00018-8

Leusch, F. D., Lu, H. C., Perera, K., Neale, P. A., & Ziajahromi, S. (2023). Analysis of the literature shows a remarkably consistent relationship between size and abundance of microplastics across different environmental matrices. Environmental Pollution, 319(December 2022), 120984. doi: 10.1016/j.envpol.2022.120984

Lorian, S., & Dagan, G. (2023). *On the sensitivity of aerosol-cloud interactions to changes in sea surface temperature in radiative-convective equilibrium*. Preprint Egusphere (October). doi: 10.5194/egusphere-2023-2096

Maity, S., Guchhait, R., Sarkar, M. B., and Pramanick, K. (2022). Occurrence and distribution of micro/nanoplastics in soils and their phytotoxic effects: A review. Plant Cell Environ. 45 (4), 1011–1028. doi: 10.1111/pce.14248

Malafaia, G., & Barceló, D. (2023). Microplastics in human samples: Recent advances, hot-spots, and analytical challenges. TrAC - Trends in Analytical Chemistry, 161. doi: 10.1016/j.trac.2023.117016

Munhoz, D. R., Harkes, P., Beriot, N., Larreta, J., & Basurko, O. C. (2022). Microplastics: A Review of Policies and Responses. Microplastics, 2(1), 1–26. doi: 10.3390/microplastics2010001

Murazzi, M. E., Cherubini, P., Brunner, I., Kägi, R., Saurer, M., Ballikaya, P., … Gessler, A. (2022). Can forest trees take up and transport nanoplastics? IForest, 15(2), 128–132. doi: 10.3832/ifor4021-015

OECD (2022) Plastic pollution is growing relentlessly as waste management and recycling fall short, says OECD. https://shorturl.at/jnvFN

Ohno, H., & Iizuka, Y. (2023). Microplastics in snow from protected areas in Hokkaido, the northern island of Japan. Scientific Reports, 13(1), 1–9. doi: 10.1038/s41598-023-37049-5

Panzavolta, T., Bracalini, M., Benigno, A., & Moricca, S. (2021). Alien invasive pathogens and pests harming trees, forests, and plantations: Pathways, global consequences and management. Forests, 12(10). doi: 10.3390/f12101364

Parolini, M., Antonioli, D., Borgogno, F., Gibellino, M. C., Fresta, J., Albonico, C., … Cavallo, R. (2021). Microplastic contamination in snow from western Italian alps. International Journal of Environmental Research and Public Health, 18(2), 1–10. doi: 10.3390/ijerph18020768

Pei, W., Hu, R., Liu, H., Wang, L., & Lai, Y. (2023). Advanced Raman spectroscopy for nanoplastics analysis: Progress and perspective. TrAC - Trends in Analytical Chemistry, 166, 117188. doi: 10.1016/j.trac.2023.117188

Rejano, F., Titos, G., Casquero-Vera, J. A., Lyamani, H., Andrews, E., Sheridan, P., … Olmo, F. J. (2021). Activation properties of aerosol particles as cloud condensation nuclei at urban and high-altitude remote sites in southern Europe. Science of the Total Environment, 762, 143100. doi: 10.1016/j.scitotenv.2020.143100

Revell, L. E., Kuma, P., Le Ru, E. C., Somerville, W. R. C., & Gaw, S. (2021). Direct radiative effects of airborne microplastics. Nature, 598(7881), 462–467. doi: 10.1038/s41586-021-03864-x,

Shaw, D. B. (2023). Ocean emission of microplastic. (October), 1–11. doi: 10.1093/pnasnexus/pgad296

Stier-Jarmer, M., Throner, V., Kirschneck, M., Immich, G., Frisch, D., & Schuh, A. (2021). The psychological and physical effects of forests on human health: A systematic review of systematic reviews and meta-analyses. International Journal of Environmental Research and Public Health, 18(4), 1–39. doi: 10.3390/ijerph18041770

Steensgaard, I., Syberg, K., Rist, S., Hartmann, N., Boldrin, A., Hansen, S.F., 2017. From macro- to microplastics - analysis of EU regulation along the life cycle of plastic bags. Environ. Pollut. 224, 289–299. https://doi.org/10.1016/j.envpol.2017.02.007

Trainic, M., Flores, J. M., Pinkas, I., Pedrotti, M. L., Lombard, F., Bourdin, G., … Koren, I. (2020). Airborne microplastic particles detected in the remote marine atmosphere. Communications Earth and Environment, 1(1), 1–10. doi: 10.1038/s43247-020-00061-y

Wang, Y., Okochi, H., Tani, Y., Hayami, H., Minami, Y., Katsumi, N., … Niida, Y. (2023). Airborne hydrophilic microplastics in cloud water at high altitudes and their role in cloud formation. Environmental Chemistry Letters, (August). doi: 10.1007/s10311-023-01626-x

Wesch, C., Barthel, A.K., Braun, U., Klein, R., Paulus, M., 2016. No microplastics in benthic eelpout (Zoarces viviparus): an urgent need for spectroscopic analyses in microplastic de- tection. Environ. Res. 148, 36–38. https://doi.org/10.1016/j.envres.2016.03.017

Zantis, L. J., Borchi, C., Vijver, M. G., Peijnenburg, W., Di Lonardo, S., & Bosker, T. (2023). Nano- and microplastics commonly cause adverse impacts on plants at environmentally relevant levels: A systematic review. Science of the Total Environment, 867(January), 161211. doi: 10.1016/j.scitotenv.2022.161211

Zeng H., Hu X., Ouyang S., Zhou Q, (2023) Microplastics Weaken the Adaptability of Cyanobacterium Synechococcus sp. to Ocean Warming Environmental Science & Technology. 57 (24), 9005-9017