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Environmental plastics in the context of UV radiation, climate change, and the Montreal Protocol

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UV radiation, climate change, and plastic pollution are closely interlinked. Existing studies on the persistence of plastics do not fully consider these linkages, challenging global assessments of plastic dispersal, persistence, and weathering. Recently, an Intergovernmental Negotiating Committee was tasked with developing an international binding agreement to end plastic pollution. In response, the UNEP Environmental Effects Assessment Panel assessed effects of UV radiation and interacting climate change factors on plastics, focusing on the durability of products as well as the production and dispersal of micro- and nano-plastic pollutants in the environment.

1 | PLASTIC POLLUTION

Annual global production of plastics was estimated at 400 million metric tonnes in 2022 (Plastics Europe, 2023). A substantial fraction of these plastics ultimately ends up in the natural environment as unmanaged and ubiquitous contaminants. Plastics are highly diverse in composition and properties. Further, their formulations typically include additives, such as dyes, flame retardants, and plasticizers, resulting in variations in chemical composition, functional and structural properties, and persistence in the environment. The environmental accumulation of plastics has led to concerns about the effects of macro- (>5 mm), micro- (<5 mm), and nano- (<0.1 μm) plastics on the health of humans and other organisms. Consequently, there is a need to better understand the environmental fate of plastic debris and especially its degradation and fragmentation into micro- and nanoplastics that can be inhaled or ingested (Abdolahpur Monikh et al., 2023).

2 | SOLAR UV RADIATION AND PLASTIC DEGRADATION

Solar UV radiation drives free-radical mediated photo-oxidation reactions that render plastics brittle and can lead to fragmentation following exposure to mechanical forces (Jansen et al., 2024) (Figure 1). Naturally occurring dissolved organic matter can further facilitate the degradation of plastics via the production of reactive oxygen species. Because of the larger surface to volume ratio of

For affiliations refer to page 3.

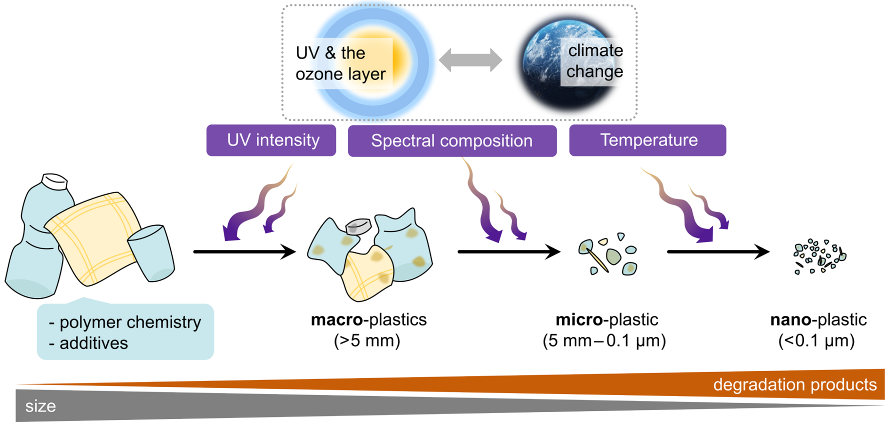

FIGURE 1 UV exposure and mechanical forces drive weathering and fragmentation of macroplastics into smaller fragments and other by-products (e.g., CO_2, CH_4, and leachates), in the air, on land, and in lakes, rivers, and oceans. Degradation depends on the chemical composition of the plastic polymer, UV intensity, UV spectral composition, and temperature. Reciprocal interactions between UV radiation and climate change impact photodegradation, making plastic degradation less predictable in the future (Modified from Jansen et al., 2024).

fragments, UV also accelerates the leaching of potentially toxic additives. The extent of UV-induced degradation of plastics in the environment depends on temperature and the intensity and spectral composition of solar UV radiation. Typically, UV-B wavelengths (280–315 nm) are more effective in oxidizing and embrittling common plastics compared to more prevalent UV-A (315–400 nm) or visible (400–700 nm) wavelengths (Zepp et al., 2023). Biological plastic degradation and/or fragmentation has also been reported, yet the global importance of this process remains to be demonstrated in natural environments.

3 | MONTREAL PROTOCOL, CLIMATE CHANGE, AND PLASTIC POLLUTION

The Montreal Protocol on Substances that Deplete the Ozone Layer, and its Amendments (hereafter referred to as the "Montreal Protocol"), have prevented widespread loss of stratospheric ozone and consequent increases in surface UV-B radiation. Without the Montreal Protocol, rates of UV-B-driven photodegradation of plastics, and consequent fragmentation, would have increased in recent decades. Correspondingly, the lifetime of plastic products exposed to solar radiation would have decreased (with associated economic and environmental costs), as would the persistence of macroplastic debris in the environment (Jansen et al., 2024).

In addition to protecting the biosphere from UV-B radiation, the Montreal Protocol provides climate change mitigation benefits through reduced emissions of ozone-depleting substances (ODS), many of which are also potent greenhouse gases (Velders et al., 2007). Furthermore, complex interactive effects between UV radiation and global climate change depend on factors such as consumer behavior, land-use (e.g., *increased use of evaporation-reducing plastic films*), wildfires and cloudiness (e.g., *affecting local UV irradiance*), dissolved organic matter in the water column (e.g., *affecting UV penetration and formation of reactive oxygen species*) and air and ocean currents (e.g., *affecting global plastic dispersal*). Furthermore, some feedstocks for plastic production are ODS that are currently exempted from the Montreal Protocol (Andersen et al., 2021). If these substances escape during plastic production, they potentially affect UV radiation, the global climate and hence the persistence of environmental plastic pollution. It is expected that the complex, interactive effects of UV radiation and climate change, together with changes in feedstocks, will make plastic weathering less predictable in the future.

4 | IN SUMMARY

Global effects of UV radiation and climate change on plastic debris present a double-edged sword: solar UV radiation and higher temperatures enhance the degradation of macroplastic debris but also lead to the generation of potentially hazardous micro- and nanoplastic particles. At present, the contribution of UV-driven weathering on the global load of micro- and nanoplastics cannot be reliably quantified due to a lack of data on rates of photo-oxidation and fragmentation in natural ecosystems. These rates are likely to be high for airborne plastics exposed to stronger UV irradiances, moderate for plastics on soil and near water surfaces, and low for plastics deeper in the water column or buried in soil where photodegradation will not occur due to the absence of UV. Future estimates of plastic persistence in the environment need to be based on existing projections of global UV radiation levels, and growing knowledge of dispersal of plastic around the globe. Such assessments will also inform the design and use of new plastics with durability matching the functional life of products, and that will mineralize into CO_2 and other gases.

AUTHOR CONTRIBUTIONS

MAKJ, ALA, PWB, RB, LER, JFB: conceptualization, investigation, and writing—original draft. All other authors: conceptualization, investigation, and writing—review and editing.

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CONFLICT OF INTEREST STATEMENT

LER conducts collaborative research with Clinuvel Pharmaceuticals Ltd and Mitsubishi Tanabe Pharma Inc. on the development of photoprotective agents. All other authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

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