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An insight into microplastic deposition rates and quality on alpine glaciers

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Introduction

Plastic materials are arguably one of the most synthetized polymers of our times and are considered strategic materials in a multitude of sectors, from building and construction to health and food. It is estimated that in 2021 in Europe were produced almost 60 million tons of plastics and the value chain of plastic products and associated businesses consisted of more than 1.5 million employees across 52’000 companies, generating an overall revenue that exceeds 400 billion euros (Plastics Europe 2023).

Unsurprisingly, throughout the last decade, plastic pollution has emerged as one of the main environmental and public health concerns of our time. Depending on their usage, plastic products can give birth to a wide range of pollutants, spanning from common visible littering to nano-sized particles characterized by a highly enhanced capability of permeating environmental matrices and biological barriers unimpeded. Specifically, particles below 5mm of diameter are considered “microplastics”, while below 1nm is the domain of “nanoplastics”, which are particularly mobile and of unpredictable interactions with cellular structures.

Plastic particles have the tendency of dispersing across scales and have been found in multiple environmental matrices such as remote alpine areas (Allen, 2019), urban settlements (Dris, 2016) marine and freshwater ecosystem (Ivleva, 2017) and in the human body (Roslan, 2024). Furthermore, it has been highlighted that the atmosphere and its dynamics constitute a major vector for particle dispersal, allowing them to reach remote areas through long range atmospheric transport (Evangeliou, 2020) where they are subjected, for example, to snow scavenging and subsequent deposition (Bergmann, 2019). It has also been shown that exposure to air induces the highest fragmentation of the original polymer when compared to marine or soil environments, further adding to the contamination and dispersal concerns (Napper, 2019).

The European Alps as a vulnerable target

Due to their central position, the high number of particle sources in their vicinities and the fragility of the ecosystem that they host, the European Alps are particularly vulnerable to microplastics contamination. Multiple studies have recently detected the presence of micro- and nanoplastics associated to different alpine matrices, such as snow pits (Materić 2025 and 2021, Parolini 2021), snow deposition (Allen, 2022) and alpine lakes sediment (Pastorino, 2023). In the biotic compartment, it has been observed that different organisms are characterized by a different microplastics “uptake”. Growth stages play a role as well, resulting for example in higher particle counts in young fish when compared to adults (Pastorino, 2023).

Polymer fragments from Polyethylene terephthalate (PET), polyethylene (PE), polypropylene (PP) are commonly detected in most studies along with polyvinyl chloride (PVC), polystyrene (PS) and tire wear particles. Originating from virtually all human activities, these particles can be (re-)suspended in the atmosphere and transported to Alpine regions, where they are still detectable as a fraction of the particulate matter (PM10, PM1). In high alpine regions, concentrations tend to vary from mass averages of 35 ng/m^3 for PM10 and 21 ng/m^3 for PM1 up to maxima of respectively 165 and 113 ng/m^3 (Austrian Alps; Kau, 2024). Multiple studies from different alpine regions report fragment counts spanning from 2.32 MP/L in the Western Italian Alps (Parolini, 2021) to 2676 MP/L in the Swiss Alps (Bergmann, 2019). Allen and coauthors (2019) investigated similar dynamics in the French Pyrenees, observing relative daily counts of 249 MP/m^2. It is general consensus that the high variability reflects local meteorology and source apportionment, with methodological discrepancies inevitably playing a role in inflating the discrepancy in the results. Air masses modeling suggests that these particles could travel up to almost 100km before reaching the final scavenging destination (Allen, 2019).

Despite the fragility of the ecosystems that characterize high alpine and glacial areas, studies addressing the ecological hazards posed by micro- and nanoplastics contamination are still in their infancy. A further problem in this sense is represented by the so-called eco-corona effect, which makes the interactions of microplastics with the biotic compartment even more unpredictable. The eco-corona effect means that particles can in fact adsorb salts, organic chemicals, heavy metals, natural organic matter and other biomolecules, generating new biochemical compounds characterized by environmental fates and toxicological profiles which can be completely different from the original polymer (Ali, 2024).

A recent investigation highlighted how plastic surfaces represent a viable colonization substrate for microbial biofilms even in harsh and volatile environments such as periglacial lakes. Mützel and coauthors (2026) identified the significant effect of different polymer surfaces in hosting different communities evolving independently throughout a 10 weeks in-situ experiment. This effect can in turn alter the unique interactions typical of these natural systems, with potential cascading effects on downstream communities.

Limitations, concerns and future perspectives

Despite being discovered only in recent years, microplastics contamination is pervasive in the environment. Investigating glacial habitats poses unique, hard to overcome challenges when compared to downstream ones. Being often out of reach and remote, it can be necessary to walk long distances to reach the sampling sites. This directly limits the sampling effort and given the necessity of relying on technical clothing, can lead to contamination of the samples in areas which are, in principle, pristine.

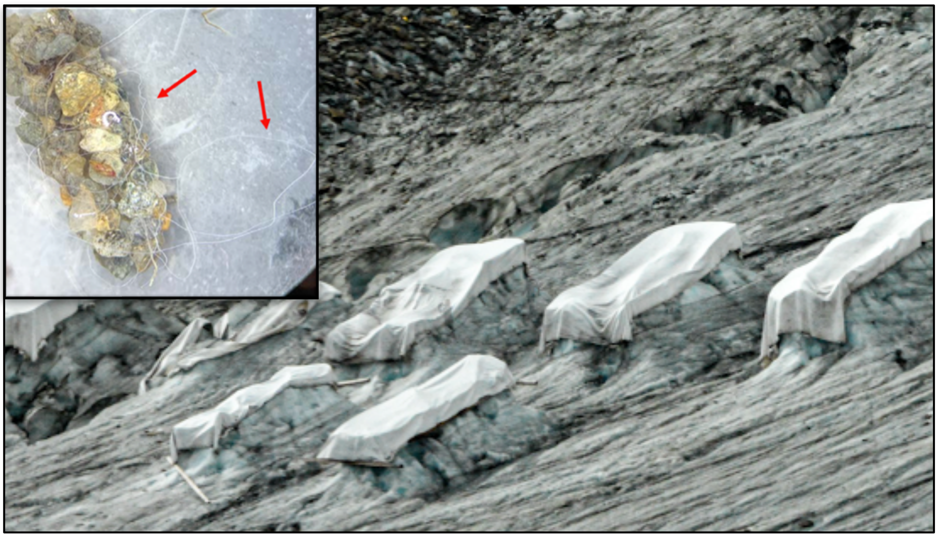

Figure 1 - Test fields on the Stubaier Gletscher, Sept. 2022 (©Birgit Sattler) and a stonefly from the downstream river entangled in fibers (© Patrick Schwenter).

Ski resorts located on alpine glaciers have been found contributing substantially to the microplastic environmental loads. Direct emissions deriving from tourism have been constituting a long-standing concern, to which the recent deployment of geotextiles adds another layer of complexity. Geotextile fleeces use has been on the rise in recent years, as a way to preserve ice foundations from melting, where infrastructure stability is in jeopardy. Subjected to strong abrasive forces typical of high alpine environments, geotextiles can tear and release fibers on the ice. Their removal is problematic as well, since they tend to stick to the snow or ice beneath. The fibers released have been observed travelling further downstream, affecting benthic communities located kilometers away from the source (Schwenter, 2023) [Fig. 1].

In similar ski resort contexts, it is therefore possible to distinguish between local and remote-source emissions, each of them presenting its own challenges. In-situ emissions related to the direct use of geotextiles on alpine glaciers may outweigh atmospheric scavenging by many orders of magnitude. It is therefore paramount to intervene locally, in collaboration with the public and the stakeholders, to implement good practices and develop materials better suited for the application, if not suspending such practices out of precaution. On the other hand, remote sources can be much harder to control. The plastics industry is a major socio-economic player in the current society, and, at the same time, analytical methods are far from converging to a consensus.

Looking forward, both local and remote sources need to be addressed to ensure lower emissions and better materials, along with solid investigation methods, embarking on the road of true social, economic and environmental sustainability.

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