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Reaching new heights in plastic pollution – preliminary findings of microplastics on Mount Everest

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Summary

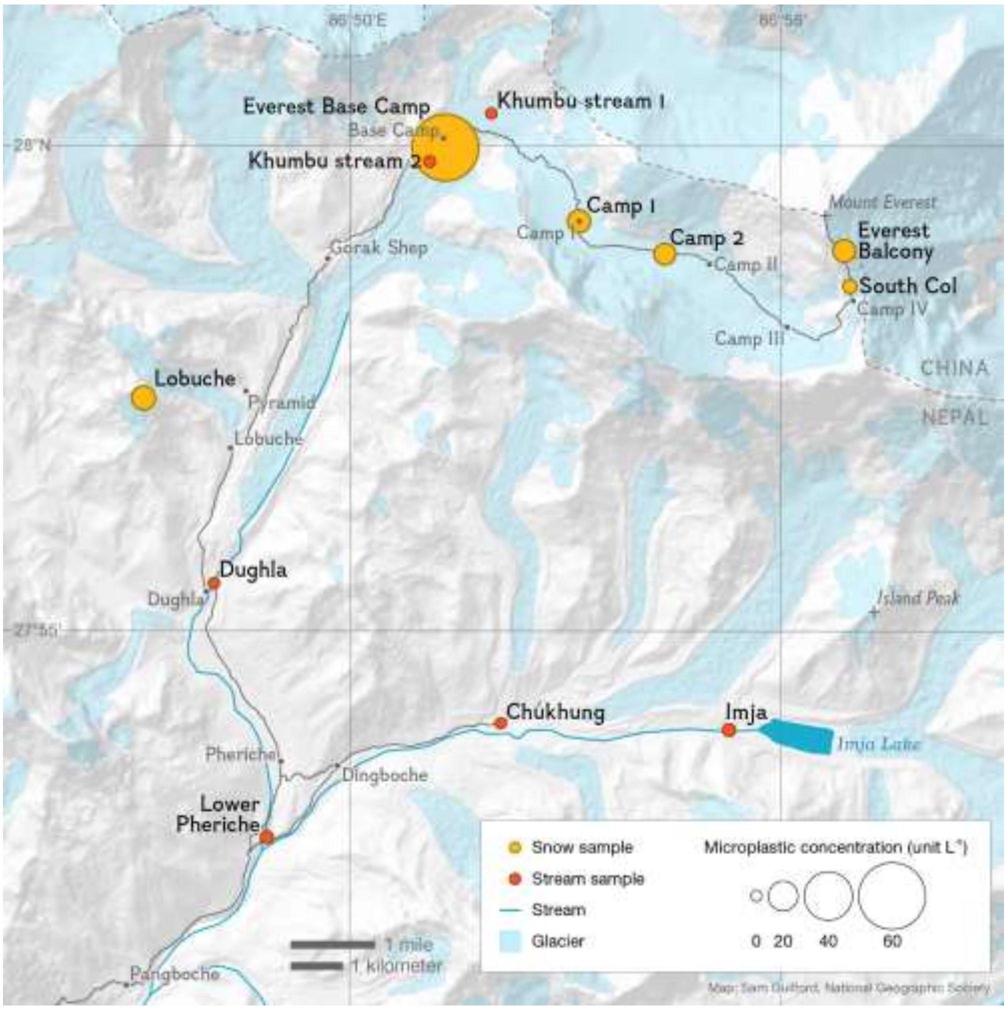
Mount Everest, Earth’s highest mountain, was once a pristine environment; however, due to increased tourism, waste is accumulating on the mountain, with a large proportion being made out of plastic. This research aimed to identify and characterise microplastic (MP) pollution at the highest point on Earth. Samples of stream water and snow were collected from areas of both high and low human presence, including a sample from the Balcony (8,440 m.a.s.l.), one of the last resting spots before the summit. MPs were detected at an estimated 30 MP L^{-1} in snow and 1 MP L^{-1} in stream water, and the majority were fibrous. MP concentration was strongly associated with areas of highest trekker footfall. Therefore, with increased tourism, deposition of MP throughout Mt. Everest is expected to rise. Consequently, at a pivotal point in the exploration of remote areas, there are lessons to be learned on how we can keep areas pristine with meaningful environmental stewardship.

Keywords

Plastic, Microfibres, Waste, Debris, Tourism, Pollution

Introduction

Mount Everest, known in Nepal and China as Sagarmatha and Qomolangma, respectively, has the highest peak in the world at 8,850 m.a.s.l. (above sea level; Figure 1)[1,2]. Sagarmatha National Park, which contains Mt. Everest, has had increasing numbers of visiting trekkers and climbers, from 3,600 visitors in 1979, to over 45,000 in 2016 [3,4]. Although increasing numbers of visitors have immensely boosted the local economy [5], the negative impacts of tourism are becoming apparent on Mt. Everest [2,6].



Map: Sam Gulford, National Geographic Society

Figure 1. ***A map of microplastic sample sites on Mt. Everest.*** *The radius of each point is relative to the microplastic concentration (light blue shows glacier extent, dark blue shows streams.*

Mount Everest's popularity to climbers began after the first known summit in 1953 and soared in the 1990s when international guides began commercial trips up the mountain [7]. Despite the risks, the mountain itself attracts hundreds of trekkers and climbers every year. In 2019, a total number of 772 climbing permits were issued in Nepal (382 member permits, 390 support permits), with 660 total climbers reaching the summit [8]. Over the decades of trekkers visiting this remote and challenging location, Mt. Everest has accumulated old tents, fixed ropes, used oxygen bottles, human waste, tins, glass, and paper left behind from previous expeditions [1]; this paper refers to all such items as waste. Waste is a long-standing problem on Mt. Everest, with the camp at the South Col (~8,000 m.a.s.l.) described as "the world's highest junkyard" over 50 years ago [1]. Subsequently, the whole mountain was described as "the highest trash dump in the world" [9].

The versatility of plastic materials has resulted in a substantial increase in their use from five million tonnes globally in the 1950s to over 330 million in 2020 [10–12]. However, the durability, versatility, low cost and wide-scale use of plastic items means that plastic litter is now prevalent worldwide, even in remote areas [13–16]. Attention has been focussed on the accumulation of microplastics (MP; <5 mm) and the quantity and potential impact of plastic on the marine environment [17,18]. It is estimated that 93,000 to 236,000 metric tons of MP to be floating on the global sea surface [19]. However, there is growing evidence that MP has also been accumulating in freshwater [20,21]and terrestrial environments [22–24].

Importantly for distal locations, MP can also be released directly to the atmosphere. Research by De Falco et al. (2020) estimated the quantity of MP fibres released into the air as a direct consequence of wearing clothes made of MP [25]. They found that 400 fibres gram^{-1} of fabric could be shed by clothing during just 20 minutes of normal activity, such as walking. Due to this, it is anticipated that atmospheric deposition of MP, especially through direct deposition from clothing, is a substantial pathway into the environment. In the atmosphere, MP can be transported long distances from their original source by wind, because of their small size and low density [26,27].

There are a variety of potential impacts plastic can have within the environment. MPs can have detrimental effects on aquatic and terrestrial organisms when ingested [28,29]. Additionally, the impacts associated with human health are still in its infancy, with MP ingestion or inhalation an emerging area of concern [30]. MPs may accumulate and exert localised particle toxicity by inducing or enhancing an immune response [31]. Chemical toxicity could occur due to the localised leaching of component monomers, endogenous additives, and potential adsorbed environmental pollutants [32,33]. There is uncertainty about the specific extent and magnitude of the harm of plastic pollution in the environment [34]. However, most researchers agree that plastic is accumulating in the environment at a concerning scale.

While the highest reaches of Mt. Everest are incredibly difficult to access for research purposes (e.g., Elvin et al.; this issue), it has been evident that waste, including visible plastic (macroplastic; >5 mm), has been accumulating on Mt. Everest for many years [1,9]. However, the quantity and variety of MP has not previously been studied. Analysing the quantity of MP in remote areas, such as Mt. Everest, helps us to identify how polluted areas are becoming from our own exploration and identify ways to mitigate that impact. The large number of trekkers and climbers visiting Mt. Everest increases the potential for the deposition of MP, as plastic is typically the main material used across the mountain. To understand whether MPs are contaminating Mt. Everest, an assessment of MP in stream water and snow samples were collected from areas of both high and low human presence. This research aims to, for the first time, quantify and describe MP pollution on the highest mountain on Earth.

Experimental Procedures

In April and May 2019, as part of National Geographic and Rolex's Perpetual Planet Everest Expedition (hereafter 2019 Everest Expedition), 19 high elevation samples were taken from the Mt. Everest region for MP analysis, with 11 from snow and 8 from stream water (Table 1; Figure 1). Approximately 900 ml of stream water and 300 ml of snow samples were placed into stainless steel metal containers. These containers had been previously cleaned in a laboratory setting with Milli-Q water, which was filtered by Whatman 1.6 µm glass microfibre filter papers. In order to minimize plastic contamination, all samples were taken from running streams (glacier meltwater) or snow (with a metal shovel or metal spoon) using un-gloved hands, then immediately sealed and stored in a box within a sampling storage tent at Everest Base Camp (5,364 m.a.s.l.).

Sample	Type of Sample	Sample Code	Latitude (°N)	Longitude (°E)	Approximate Distance from the Trail (m)	Approximate Elevation (m.a.s.l.)	Date Collected
1	Snow	Everest Base Camp [a]	28.0039	86.8586	150	5,300	01/05/2019
2	Snow	Everest Base Camp [b]	27.9997	86.8517	150	5,300	06/05/2019
3	Snow	Everest Base Camp [c]	27.9997	86.8516	150	5,300	09/05/2019
4	Snow	Camp I [1]	27.9871	86.8776	100	6,000	07/05/2019
5	Snow	Camp I [2]	27.9871	86.8776	100	6,000	07/05/2019
6	Snow	Camp II [1]	27.9815	86.8942	100	6,500	07/05/2019
7	Snow	Camp II [2]	27.9815	86.8942	100	6,500	07/05/2019
8	Snow	South Col	27.9759	86.9300	100	8,000	22/05/2019
9	Snow	Balcony	27.9821	86.9289	5	8,440	23/05/2019
10	Snow	Lobuche [1]	27.9567	86.7933	50	5,875	09/05/2019
11	Snow	Lobuche [2]	27.9567	86.7933	50	5,875	09/05/2019

12	Stream	Khumbu Stream 1 [1]	28.0056	86.8606	250	5,215	08/05/2019
13	Stream	Khumbu Stream 1 [2]	28.0056	86.8606	250	5,215	08/05/2019
14	Stream	Khumbu Stream 2 [1]	27.9975	86.8478	150	5,240	09/05/2019
15	Stream	Khumbu Stream 2 [2]	27.9975	86.8478	150	5,240	09/05/2019
16	Stream	Dugla	27.9100	86.8033	150	4,800	14/05/2019
17	Stream	Lower Pheriche	27.8809	86.8174	100	4,200	14/05/2019
18	Stream	Chhukung	27.9008	86.8625	100	4,600	05/05/2019
19	Stream	Imja	27.8997	86.9067	100	5,000	09/05/2019

Table 1; *Descriptions and locations of the snow and stream samples taken for analysis for microplastic from Mt. Everest. Numbers in brackets signify the replicates.*

To determine the contribution of atmospherically deposited MP, we sampled 11 snow locations for plastic deposition at Everest Base Camp, Mt. Lobuche and along the climbing route to the summit of Mt. Everest (Figure 1). All snow samples were collected within ~ 5 cm of the surface.

At Everest Base Camp, the first fresh snow sample was collected in the morning following a light snowstorm the evening prior. This sample was taken from within the penitentes (snow and ice formations found at high altitude) on the Khumbu Glacier in an undisturbed area about 150 m from the closest tent. Two additional samples were collected (Everest Base Camp b & c) close to this location (Figure 1).

Above Everest Base Camp, climbers follow a narrow, prescribed path up to the summit. Along this climbing route, the Camp I (5,943 m.a.s.l.) snow samples were obtained 100 m west from a collection of tents. At Camp II (~6,400 m.a.s.l.), the snow samples were taken from the western section of the glacial valley between

Camp I and II. This surface snow sample from Camp II represents the most recent precipitation from all the samples; it was taken immediately after snowfall. There was also visible waste at Camp II. The South Col sample (~8,000 m.a.s.l.) was 100 m away from the climbers' route. Our highest sample was from ~50 m above the Balcony (~8,440 m.a.s.l.), where the steep slopes and rock walls prevented sampling farther than ~5 m from the path (Figure 2). The Balcony is highly impacted by climbers and utilized as a popular resting spot during the final summit push; large amounts of food waste, oxygen bottles, and general trash were within view of the sampling location. Additional samples were collected at Mt. Lobuche (5,875 m.a.s.l.), a popular trekking peak nearby, ~50 m from the climbers' path and ~300 m from the closest camp.

Figure 2. Mt. Everest Balcony - High-elevation climbers and Sherpa wearing 'Himalayan suits' made of waterproof acrylic fibers at the Balcony (~8,430 m.a.s.l.) In the background, disused metal oxygen canisters and other waste can be seen at this common resting point. The prescribed climbing continues in the background and a

long line of climbers can be seen ascending. The approximate location of the Balcony MP sample is shown by the red arrow (Photo credit: Baker Perry/National Geographic).

The stream water samples were taken from 6 locations (Figure 1; Table 1), including glacier meltwater (2), and stream surface water from the Khumbu (2) and Imja (2) valleys. To determine the MP quantity at the head of the watershed, we sampled two locations from the Khumbu Glacier meltwater stream, close to Everest Base Camp. Khumbu Stream 1 (~5,215 m.a.s.l.) samples were collected from a meltwater stream located north-west of the Khumbu icefall and south-east of Everest Base Camp. To retrieve these samples, the members of the 2019 Everest Expedition trekked south-east of Everest Base Camp onto the Khumbu glacier, through penitentes, and across debris mounds (~ 250 m from closest camp). This site and along the trek was riddled with recent (e.g., plastic bottles, candy wrappers) and dated (e.g., rusted metal) human-made products.

Dated materials are presumably due to waste from higher elevation camps being transported through the Khumbu icefall. Khumbu Stream 2 (~5,240 m.a.s.l.) samples were collected from a meltwater stream formed between penitentes on the Khumbu glacier, located on the south-west side of Everest Base Camp, about 200 m away from the nearest camp. Compared to the prior site, less human-made waste was visible proximally, however fragments of unknown plastic and candy wrappers were found.

Samples were collected from two stream locations, Dugla and Lower Pheriche, along the main path to Everest Base Camp in the Khumbu valley, fed predominantly by Khumbu glacier meltwater (Figure 1). The Dugla (~4,800 m.a.s.l.) samples were collected ~150 m north-west of the Dugla settlement and about ~50 m north of the path. The Lower Pheriche samples (~4,200 m.a.s.l.) were collected ~1,200 m downstream of the Pheriche village and ~50 m north of the path.

We additionally collected samples from the Imja valley, adjacent to the Khumbu, fed predominantly by the Imja glacier. The Chukkung samples (~4,600 m.a.s.l.) were collected from a stream ~50 m from the path leading to Chukkung village, located

~1,000 m north-east from the sample site. The Imja samples (~5,000 m.a.s.l.) were collected at the outlet of Imja Lake, ~3,500 m east of the Chukkung village. Minimal, scattered waste was visible at these locations.

All samples were shipped to the University of Plymouth after the 2019 Everest Expedition. In the laboratory, melted snow and stream water were vacuum filtered directly from the sampling containers onto Whatman 1.6 µm glass microfibre filter papers and the filtered volume recorded. The filter papers were examined using a S9E - Leica light microscope and potential synthetic MP were manually removed. Information on the types of MP, dimensions by graticule measuring (length and diameter), and colour were recorded. Any suspected MP was confirmed by Fourier-Transform Infrared Spectroscopy (FTIR) microscopy in transmission mode with a Hyperion 1000 microscope coupled to a Bruker Vertex 70 spectrometer. For each suspected MP item, the spectra were recorded with 32 scans in the region of 4,000 to 600 cm. The spectra obtained were compared against a spectral database of synthetic polymers (BPAD polymer & synthetic fibres ATR) to identify MP type.

During any laboratory analysis, all steps were conducted in purpose-built microplastics clean laboratory; which had a positive pressure air system, limited and controlled access, and procedural blanks. Cotton laboratory coats and clothes were worn to reduce contamination from synthetic textiles. All laboratory ware was made of glass or stainless steel and thoroughly rinsed with filtered 1.6 µm Milli-Q water before use. To account for possible contamination from the stainless-steel metal containers, five procedural blanks were created in the laboratory by filling the stainless containers with 500 ml of filtered Milli-Q water. Then, all blanks were processed in the same way as the snow and stream samples. No visible contamination was reported from the laboratory blanks.

The number of MP in each sample was calculated per litre, so that the volume was standardised. A general linear model was carried out to assess the difference in the MP abundance in samples taken from different sample type (snow or stream). To fit the assumptions of the model, a quasi-poisson distribution was used [35]. To assess the model fit, sample against residuals and quartile-quartile plots were visually inspected. The same methodology was also applied for analysing the differences in

MP dimensions (length and width) across the different sample and polymer types. Due to the scarcity of spatial replication in the data collected, concentration changes with distance from Everest Base Camp could not be statistically assessed with confidence. However, a visual assessment was carried out using the "'ggplot2' package within R [36].

Results

MP was found in each of the snow samples, ranging from 3 – 119 MP L^{-1}, with an average of 30 ± 11 MP L^{-1} (mean ± S.E.) (Figure 1; Table 1); the highest concentration of MP was in Everest Base Camp Sample a, and the lowest was at the South Col. Taking into consideration any averaging of replicates and listed in order of increasing altitude, 79 MP L^{-1} was found in the snow at Everest Base Camp, 13 MP L^{-1} at Camp I, 11 MP L^{-1} at Camp II, 14 MP L^{-1} at Lobuche and 3 MP L^{-1} at South Col. The highest sample, at the Balcony, had 12 MP L^{-1}.

Out of 56 MP found in snow samples (approximately 3.3 L snow water equivalent in total), the majority (53) were fibrous, and 3 were fragments (Figure 3). Fragments were only found in samples from Lobuche (2 nylon fragments and 1 polyester fragment). The snow samples had significantly more MP per litre than the stream samples ($p < 0.0001$; Figure 5A).

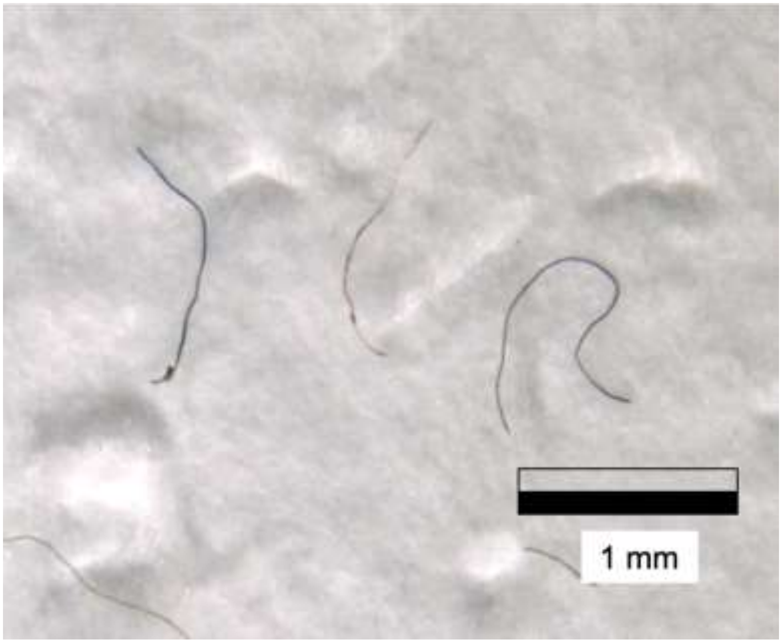


Figure 3. A selection of microfibers found in snow samples from Mt. Everest Base Camp (8,040 m), which are consistent with fibres from outdoor clothing.

Less than half (3 of 8 samples) of the stream samples had MP present, where samples ranged from 0 – 2 MP L^{-1}, with an average of 1 ± 0.3 MP L^{-1} (Figure 4). Taking into consideration any averaging of replicates, the Lower Pheriche and Imja had the most, at 2 MP $L^{-1,}$ and Khumbu Stream 2 had 1 MP L^{-1}. In contrast, no MP were found in Chhukung, Dugla, and Khumbu Stream 1. Only 5 fibrous MP were found in total. The fact that no MP were found in three of the stream samples, indicates that there were successful contamination controls.

Snow samples had a more diverse range of polymer types (polyester, acrylic, nylon, and polypropylene) than the stream samples (polyester and acrylic). Across both snow and stream samples, polyester was the most abundant polymer found (56 %), followed by acrylic (31 %), nylon (9 %) and polypropylene (5 %; Figure 4B).

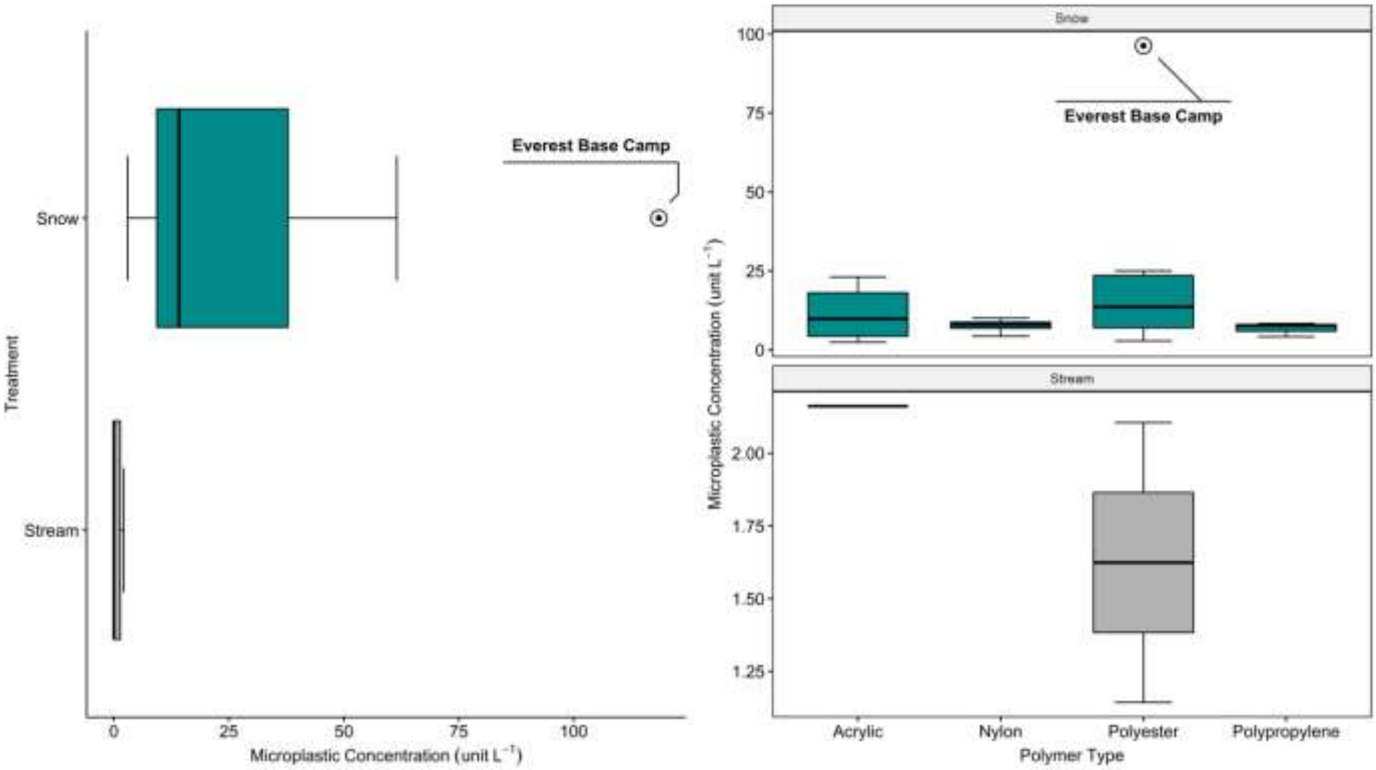


Figure 4. Concentration and polymer type of microplastics on Mt. Everest.

Boxplots showing the microplastic concentration in snow and stream samples (A- cumulative concentration & B- comparing different polymer types).

The size of MP detected from snow and stream samples were between 36 - 3,800 µm in length, and 18 – 2,000 µm diameter (Figure 6). The length of different polymer MPs across snow and stream samples showed high levels of variation, especially within snow (Figure 5A). However, the variation was not statistically significant ($p = 0.2203$). In contrast, the width of different polymers showed little variation across polymers or sample type, except for two much wider polyester particles ($p = 0.4280$) (Figure 5B). The effect of different polymers on length or width was also not significant ($p = 0.2611$ and 0.3326, respectively).

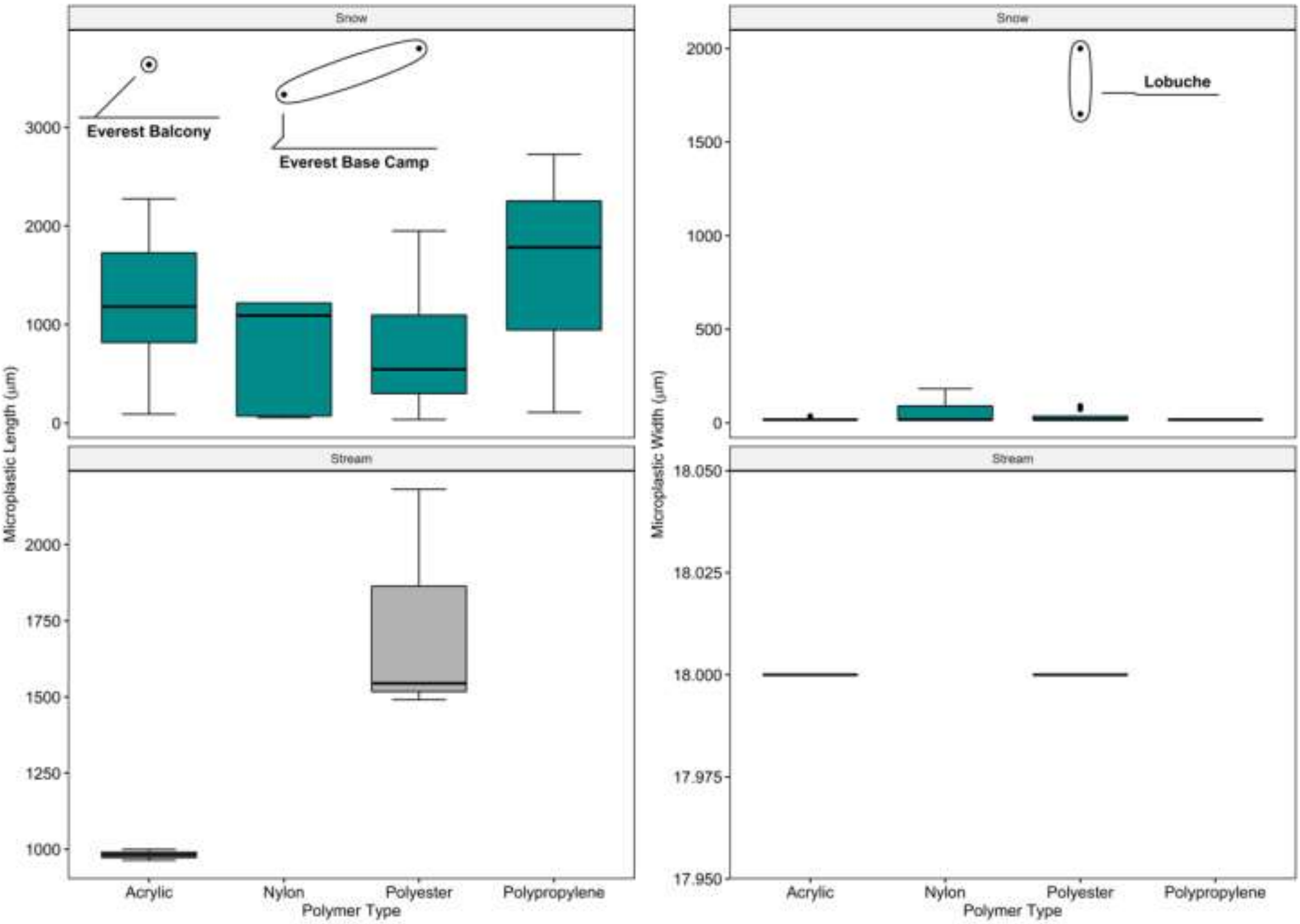


Figure 5. Characteristics of Mt. Everest Microplastics: *Boxplots showing the microplastic dimensions in micrometres (A- Length left & B- Width right) of polymer types across snow and stream samples.* The majority of microplastics found were microfibres.

While we are aware that the number of snow and stream samples collected is relatively small, we note firstly that these unique preliminary samples were incredibly difficult to collect (e.g., Elvin et al., this issue). Shipping constraints required that the sample containers be transported to and from the mountain by helicopter, which is costly and has both weight and volume limitations. Thus, the number of sampling containers available had to be limited. Further, for all samples collected above Everest Base Camp, there was a significant burden of hand-carrying both the empty containers up the mountain and the filled containers down the mountain. Despite the limited number of samples analysed here, our MP results are statistically robust, including with replicates, and suitably demonstrate the utility of this method that has never been applied in this region. Importantly, this preliminary MP analysis demonstrates that MP are significantly abundant in this region to necessitate additional and comprehensive further study.

Discussion

Our research reports an important initial assessment of MP contamination on Mt. Everest, with an estimated 30 MP L^{-1} in snow. The snow samples had significantly more MP compared to stream samples. This may be due to the stream constantly moving, and having greater dilution from the melting glaciers, versus the more static snow. In the atmosphere, snow binds airborne particles and pollutants, which are eventually deposited on Earth's surfaces, a phenomenon termed "scavenging" [37]. Bergmann et al., (2019) found that the MP concentration of Arctic snow was significantly lower (0 to 14,400 MP L^{-1}) than European snow (190 to 154,000 MP L^{-1}) [38]. However, MP detected in snow samples from the Swiss Alps were at 190 MP L^{-1} are more similar to our results and suggest that altitude, and/or prevalence of tourism may affect MP concentration [38].

Previous research by Dris et al. (2015) found 29–280 MP m^{-2} day^{-1} from atmospheric fallout in Paris, France [39]. More than 90 % of MP observed were fibres, which is consistent with our results showing dominantly fibrous MP. Similar work by Wright et al. (2020) showed deposition rates in London (UK) ranged from 575 to 1,008 MP m^{-2} day^{-1}, with fibrous MP accounting for the majority (92 %)[40]. Allen et al. (2019) also analysed atmospheric MP deposition in a remote, pristine mountain catchment in the French Pyrenees [26]. However, according to a publicly available global dataset compiled by Adventure Scientists, the highest elevation sample to be examined for MP prior to this study is from 5,776 m.a.s.l., from a glacier lake below Mount

Shishapangma in Tibet; that snow sample contained ~22 MP L^{-1}, including red, black, and blue fibres [41].

Mount Everest is located far away from major populations or industrial centres and is difficult to access; the nearest city is Kathmandu, which is 160 km away. Yet, the average MP deposition for snow recorded at our sites was 30 ± 11 MP L^{-1}. Our preliminary work shows that MP concentrations were at higher levels in snow samples taken near trekker resting spots, or sites of the increased footfall of trekkers/climbers. MP abundance was highest around Everest Base Camp (~70 MP L^{-1}), where the majority of trekkers and climbers spend considerable time, from 1 to over 40 days. All other samples were lower in MP concentration on hiking routes and camps at higher altitudes (~12 MP L^{-1}). This includes the sample from the Balcony, which was taken ~5 m from the path (Figure 3); this is the highest known sampling point for MP. The lowest concentration was from South Col (3 MP L^{-1}), which was taken the furthest away from a camp and path (~100 m distance).

Figure 6. Mt. Everest Camp IV - High-elevation camping tents at the South Col/ Camp IV (~7,925 m.a.s.l.), which are made of waterproof acrylic material. In the background, climbers wearing plastic-based waterproof outdoor gear are following the prescribed climbing route up toward the summit (Photo credit: Mariusz Potocki/National Geographic).

The size of MPs detected in our research ranged between 36 - 3,800 μm in length. This was similar to research by De Falco et al., (2020), who estimated the quantity of MP fibres released into the air directly as a consequence of wearing clothes [25]. They found the lengths of MP fibres released from clothing ranged from 494 - 1,036 μm. Furthermore, their research estimated that 1 billion MP could be released from a person wearing 1 kg (e.g., a coat) of polyester clothing per year, equating to 2.8 million MP released per day [25]. Such a finding implies that previous estimations of MP pollution in environmental samples are likely to be underestimated from the shedding of synthetic textiles into atmospheric deposition. The amount released from clothing will depend on fabric type and clothing style.

The polymers found in Mt. Everest samples were polyester (56%), acrylic (31%), nylon (9%), or polypropylene (5%) (Figure 5). These polymer types are used to make the majority of outdoor gear, where polyester, acrylic, and polypropylene are standard fibres for clothing [42]. Polyester and nylon are also popular materials for tents and climbing ropes. This material is high quality, affordable, and can be modified for outdoor use with other chemicals (i.e., incorporating water resistance). The rise in the use of outdoor clothing made from plastic within the last decade will have had an impact on MP accumulation over this period.

Additionally, the wind may be transporting such plastics from other locations; for example, large dust particles are transported over distances of 3,500 km from the Sahara to the North Atlantic [43]. Air mass trajectories have also previously suggested that MP had transported over a distance up to 95 km [26]. Brahney et al. (2020) show that even the most isolated areas in the United States, national parks and national wilderness areas, can accumulate MP particles after they are transported there by wind and rain; they estimate that more than 1,000 metric tons per year fall within south and central western U.S. protected areas [27]. Windblown MP are increasingly possible in this region, given that the Mt. Everest often sees prolonged strong winds, especially on its upper reaches.

While our preliminary results show significantly lower concentrations of MP in stream samples than in surface snow samples (Figure 1), we note that our sampling for this study occurred during the pre-monsoon period [44] and thus we are not able to capture any potential seasonal variations. However, during the pre-monsoon period, glacial meltwater, like the samples described herein, contribute an average of 65 % of domestic water to the people of the Khumbu region [45]. Therefore, even the relatively low concentrations of MP we found in our limited river samples could therefore be directly consumed by some of the up to 6,000 local community members who reside in the Khumbu Valley [2,46,47]. Additionally, the processes differentiating snow and water MP concentrations remain elusive. If MP preferentially remain on snow covered glaciers, then the increasingly high rate of melting glaciers in high mountains in Asia [48] could result in increasing MP found in the downstream meltwater as glaciers recede. While our number of samples is limited by the difficulty of collecting these unique and ultra-high elevation samples, this study lays important groundwork for subsequent expanded examinations of MP in the region. A deeper understanding of the risks to local populations from meltwater MP is needed and more samples and analyses will be required to gain a full understanding of this critical issue.

Human activities leading to preferential choices of gear containing plastics are impacting Mt. Everest. During the 2019 Everest Expedition, waste of suspected recent deposition was directly observed, as well as debris from previous climbing seasons. This included discarded plastic bottles, food wrappers, oxygen bottles, food waste, and cigarette butts. The Nepalese government and the Sagarmatha Pollution Control Committee have previously launched debris removal operations [49]. In 2019, the Nepalese Army cleared about 10,000 kg of waste from the region [50]. Other operations are also in place to further mitigate the issue of visible waste deposition in the region. For example, Nepal's government has brought in measures to encourage people not to litter, asking for a US$4,000 deposit, which is returned if they bring their waste back down with them [50]. They have also banned single-use plastics in the region from January 2020 in a bid to cut down on waste left by climbers [51].

Further solutions for addressing plastic pollution will require choices in environmental options from industry and coordinated actions across a number of sectors/stakeholders [34].

Analysing the quantity of microplastic in remote areas, such as Mt. Everest, helps us to identify how polluted areas are becoming from our own exploration. As discussed, larger items of plastic are being accounted for with waste management and new policies and procedures. Additionally, due to being more visible, such waste can be removed and appropriately managed if discarded. However, MPs are just as persistent and typically more difficult to remove, but often not considered as they are less visible. An important finding in this study is that the MPs are coming primarily from clothing, rather than resulting from the breakdown of macroplastics. This new insight gives a new focus for consideration at a pivotal point in the exploration of remote areas, with lessons to be learned on how we can keep areas pristine with meaningful environmental stewardship. Currently, environmental stewardship is focussed on reducing, reusing and recycling larger items of waste. Although these actions are necessary and important, it is evident that solutions need to expand into deeper technological and novel advances with focus on microplastics. For example, it has been suggested by Napper et al., (2020)[34] that reducing shedding through changes in fabric design could be a more overarching mitigation strategy, as this is likely to help reduce emissions during all use phases: wearing, washing and tumble drying [25,42,52]. Another example includes a switch from synthetic to natural textiles. However, replacing synthetic textiles with natural counterparts could be more expensive and the impact of non-synthetic microfibres accumulating in the environment is currently unclear [54]. It would be useful to engage the manufacturers of performance clothing used by climbers and trekkers in a dialogue to explore how these findings could be considered in clothing design and development, especially as many of these companies have active existing environmental agendas.

Additional policy action should focus on known specific sources of MP pollution. As one example, some facial cleansers, facial scrubs or exfoliants, have been identified as a source of plastic pollution because they may contain polyethylene (PE) microbeads [32,53]. Previous research by Napper et al. (2015)[32] found that over three million microplastic pieces could be in one facial scrub bottle. Subsequently, microbeads have been banned in many countries, including the United Kingdom and the U.S.A. [55,56] and natural alternatives have had to have been sourced or developed. Advancements in industry coupled with legislation is required to keep remote natural areas protected. As such, some of the key challenges now lie, not in environmental science to help understand the problem, but robust evidence to inform appropriate solutions, combined with engagement with those industries to drive change.

CONCLUSIONS

MP contamination has been found from the bottom of the sea [57] to near the top of the world's highest mountain, according to our new results, highlighting the global importance of MP debris to the environment. Despite Mt. Everest's high altitude and location away from major population centres, both macro and MP were detected in the area by this study, including the highest MP ever recorded, MPs were strongly associated with areas of highest footfall and likely originated from clothing. In order to protect the environment and communities downstream, individuals who participate in adventure travel and extreme sports, like trekking and climbing, must continue to minimize their impact, especially when concerning harmful debris. In remote and pristine areas, current mitigations to limit plastic pollution typically focus on visible waste, but there has been limited focus on the impact of MP. With the increasing number of trekkers and climbers per year, the accumulation of both visible debris and MP is expected to rise, potentially increasing MP contamination throughout the Khumbu region. It is evident that microplastics are ubiquitous throughout most environments, so now we must focus on robust evidence to inform appropriate solutions.

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Declaration of Interests

The authors declare no conflict of interest.

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