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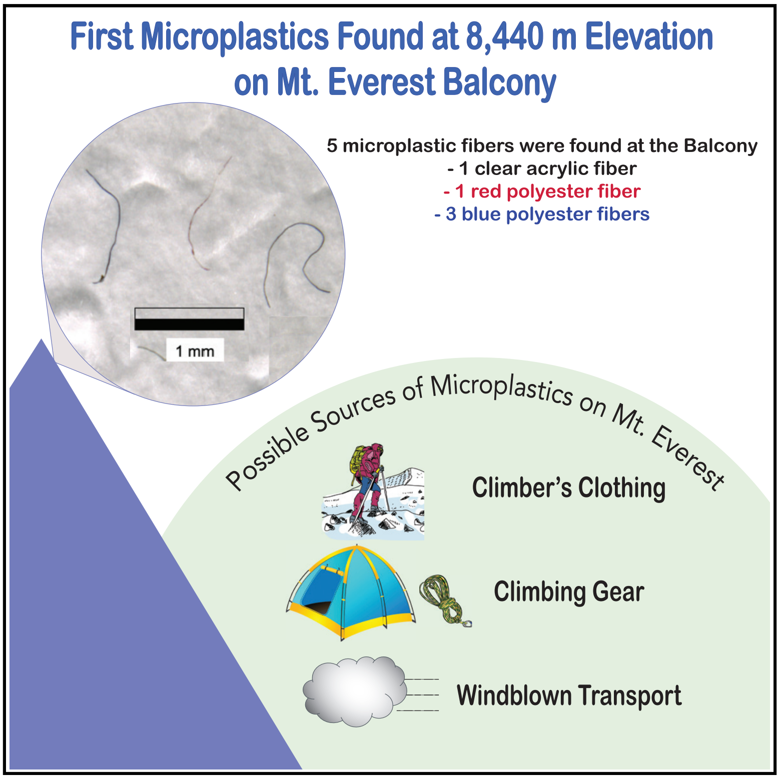
# Reaching New Heights in Plastic Pollution—Preliminary Findings of Microplastics on Mount Everest

## Graphical Abstract




## Highlights

- Microplastics were found in snow and stream water samples on Mt. Everest
- The highest microplastics were discovered in a sample from 8,440 m.a.s.l.
- Most microplastics were polyester fibers, likely from clothing and equipment
- Technological advances could minimize microplastic pollution from exploration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## In Brief

An analysis of snow and stream water on Mt. Everest up to 8,440 m.a.s.l. found microplastics (<5 mm) that were more concentrated near high human presence. Most of these microplastics were polyester fibers, likely to come from clothing and equipment. Exploration of extreme, remote environments requires appropriate stewardship, including progressing technological advances in gear design and minimising specific sources of plastic pollution.


Napper et al., 2020, One Earth *3*, 621–630

https://doi.org/10.1016/j.oneear.2020.10.020

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# Reaching New Heights in Plastic Pollution—Preliminary Findings of Microplastics on Mount Everest

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https://doi.org/10.1016/j.oneear.2020.10.020

**SCIENCE FOR SOCIETY** Plastic pollution is a key issue of our time, with the environmental impacts of this remarkable material increasingly the focus of interventions ranging from grassroots clean-up initiatives to product re-design and international policies. In this paper, we provide the first documentation of the likely presence of microplastics in snow and stream water on Mt. Everest, including near regions of high human presence, such as near climbing paths. These tiny plastic pieces (<5 mm) were mainly polyester fibers, likely coming from climber's clothing and equipment. These findings highlight human impacts in Earth's remotest areas, partly through the act of exploration of extreme environments. This creates a challenge and opportunity for manufacturers of performance clothing and equipment to develop designs that use more sustainable materials that are either natural or minimize shedding of microplastics. Climbers and trekkers should consider the full impact of exploration activities on the environment.

## SUMMARY

Mount Everest was once a pristine environment. However, due to increased tourism, waste is accumulating on the mountain, with a large proportion being made of plastic. This research aimed to identify and characterize microplastic (MP) pollution near the top of highest mountain on Earth and could illustrate the implications for the environment and the people living below. Stream water and snow were collected from multiple locations leading up to, and including, the Balcony (8,440 m.a.s.l). MPs were detected at an ~30 MP $L^{-1}$ in snow and ~1 MP $L^{-1}$ in stream water, and the majority were fibrous. Therefore, with increased tourism, deposition of MP near Mt. Everest is expected to rise. At a pivotal point in the exploration of remote areas, environmental stewardship should focus on technological and other advances toward minimizing sources of MP 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. (meters 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 on Mt. Everest are becoming apparent and have been noted for several years;[2,6] however, the environmental impacts of microplastic (MP) on Mt. Everest have not been examined.

Mt. 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

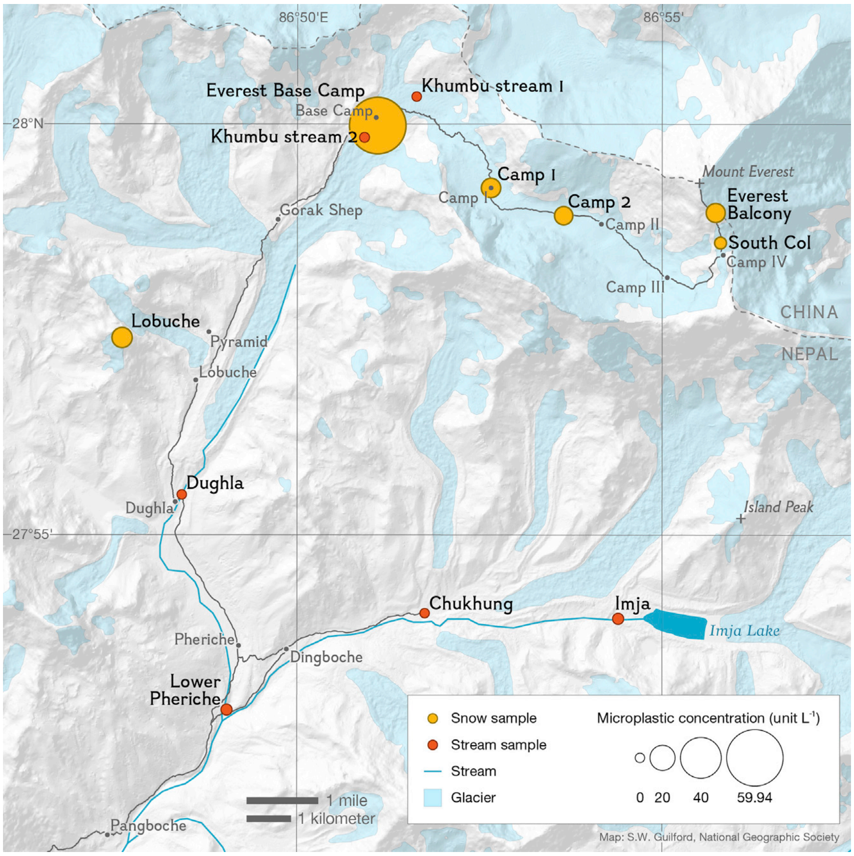


**Figure 1. A Map of Microplastic Sample Sites in the Mt. Everest Region**

The radius of each point is in relation to the microplastic concentration (Table S1). Light blue shows glacier extent, dark blue shows streams and lakes, and the gray line shows the general trekking path.

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), and 660 total climbers reached 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; the camp at the South Col (~8,000 m.a.s.l.) was described as "the world's highest junkyard" over 50 years ago[1] and the whole mountain described as "the highest trash dump in the world."[9] Yet, there have been no assessments of MP in the Mt. Everest region to date.

Increasing in popularity at the same time as Mt. Everest's climbing, the versatility of plastic materials has resulted in a substantial increase in their use from 5 million tonnes globally in the 1950s to over 330 million in 2020, predominately due to the increased use of single-use plastics.[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.[13–21] Globally, attention has been focused on the accumulation of MP (<5 mm) and the quantity and potential impact of plastic on the marine environment.[22,23] It is estimated that 93,000–236,000 metric tons of MP is now floating on the global sea surface.[24] However, although there are not yet agreed-upon thresholds for MP that constitutes dangerous concentrations of MP for people, species, or the environment, there is growing evidence that MP has also been accumulating at significant concentrations in freshwater[25,26] and terrestrial environments.[27–29]

MP can also be released directly to the atmosphere, and thus they have the potential to reach Mt. Everest through wind currents and direct deposition. Research by De Falco et al.[30] estimated the quantity of MP fibers released into the air as a direct consequence of wearing clothes made of MP. They found that 400 fibers gram$^{-1}$ of fabric could be shed by clothing during just 20 min of normal activity, such as walking. Because of 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.[31,32] A majority of technical clothing, such as that worn by trekkers and climbers on Mt. Everest, is made of synthetic fabrics.

There are a variety of potential impacts that MPs can have within the environment, including detrimental effects on aquatic and terrestrial organisms when ingested.[33,34] Additionally, although MP impacts associated with human health are still in its infancy, MP ingestion or inhalation are an emerging area of concern,[35,36] especially given that other species have been shown to bioaccumulate MP in their tissue. If ingested, microparticles, (such as MP), could accumulate and exert localized particle toxicity by inducing or enhancing an immune response.[31] Chemical toxicity could occur due to the localized leaching of component monomers, endogenous additives, and potential adsorbed environmental pollutants.[37,38] There is uncertainty about the specific extent and magnitude of the harm of plastic pollution in the environment.[39,40,41,42]

Although the highest reaches of Mt. Everest are incredibly difficult to access for research purposes, it has been evident that visible plastic (microplastic, > 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. Analyzing the quantity and characteristics of MP in remote areas, such as Mt. Everest, helps identify the impact of human actions on the pollution of remote areas. A large number of trekkers and climbers visit Mt. Everest, which increases the potential for the deposition of MP because plastic is the main material used and discarded across the mountain. To establish the concentration of MP contamination on Mt. Everest, an assessment of MP in stream water and

**Table 1. Descriptions and Locations of the Snow and Stream Samples Taken for Analysis for Microplastic from Mt. Everest**

| Type of Sample | Sample Code | Latitude (°N) | Longitude (°E) | Approximate Distance from the Trail (m) | Approximate Elevation (m.a.s.l.) | Collection Date (DD/ MM/YYYY) |
|---|---|---|---|---|---|---|
| Snow | Everest Base Camp [1] | 28.0039 | 86.8586 | 150 | 5,300 | 01/05/2019 |
| Snow | Everest Base Camp [2] | 27.9997 | 86.8517 | 150 | 5,300 | 06/05/2019 |
| Snow | Everest Base Camp [3] | 27.9997 | 86.8516 | 150 | 5,300 | 09/05/2019 |
| Snow | Camp I [1] | 27.9871 | 86.8776 | 100 | 6,000 | 07/05/2019 |
| Snow | Camp I [2] | 27.9871 | 86.8776 | 100 | 6,000 | 07/05/2019 |
| Snow | Camp II [1] | 27.9815 | 86.8942 | 100 | 6,500 | 07/05/2019 |
| Snow | Camp II [2] | 27.9815 | 86.8942 | 100 | 6,500 | 07/05/2019 |
| Snow | South Col | 27.9759 | 86.9300 | 100 | 8,000 | 22/05/2019 |
| Snow | Balcony | 27.9821 | 86.9289 | 5 | 8,440 | 23/05/2019 |
| Snow | Lobuche [1] | 27.9567 | 86.7933 | 50 | 5,875 | 09/05/2019 |
| Snow | Lobuche [2] | 27.9567 | 86.7933 | 50 | 5,875 | 09/05/2019 |
| Stream | Khumbu Stream 1 [1] | 28.0056 | 86.8606 | 250 | 5,215 | 08/05/2019 |
| Stream | Khumbu Stream 1 [2] | 28.0056 | 86.8606 | 250 | 5,215 | 08/05/2019 |
| Stream | Khumbu Stream 2 [1] | 27.9975 | 86.8478 | 150 | 5,240 | 09/05/2019 |
| Stream | Khumbu Stream 2 [2] | 27.9975 | 86.8478 | 150 | 5,240 | 09/05/2019 |
| Stream | Dugla | 27.9100 | 86.8033 | 150 | 4,800 | 14/05/2019 |
| Stream | Lower Pheriche | 27.8809 | 86.8174 | 100 | 4,200 | 14/05/2019 |
| Stream | Chhukung | 27.9008 | 86.8625 | 100 | 4,600 | 05/05/2019 |
| Stream | Imja | 27.8997 | 86.9067 | 100 | 5,000 | 09/05/2019 |

Numbers and letters in brackets signify replicates. Data from the samples can be found in Tables S1 and S2.

snow samples (Figure 1; Table 1) was undertaken during April–May 2019, including up to the Balcony (8,440 m.a.s.l.) (Figure 2). Samples were then carefully quantified and individual MP fragments were described according to their physical characteristics (see Experimental Procedures). This research aims to, for the first time, quantify and describe MP pollution on the highest mountain on Earth.

## RESULTS

Mt. Everest samples indicate that MP is ubiquitous in the region, and MP was found in each of the snow samples, at levels ranging from 3 to 119 MP $L^{-1}$ and an average of 30 ± 11 MP $L^{-1}$ (mean ± SE) (Figure 1; Table 1; Table S1); the highest concentration of MP was in Everest Base Camp Sample (1), 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 (Figure 3), and 3 were fragments (Table S2). Fragments were only found in samples from Lobuche (2 nylon fragments and 1 polyester fragment).

Compared with the snow samples, the stream samples had significantly less MP per liter ($p < 0.0001$) (Figure 4A). Less than half (3 of 8 samples) of the stream samples had MP present, where samples ranged from 0 to 2 MP $L^{-1}$ and 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 highest concentrations at 2 MP $L^{-1}$, and Khumbu Stream 2 had 1 MP $L^{-1}$. In contrast, no MP was found in Chhukung, Dugla, and Khumbu Stream 1. Only 5 fibrous MPs were found in total from the stream samples. However, MP concentration in both snow and stream samples might be an underestimation as the minimum particle size was > 30 μm. Therefore, anything smaller than 30 μm was not included in analysis.

Snow samples not only had higher concentrations of MP, they also 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).

The size of MP detected from snow and stream samples were between 36 and 3,800 μm in length, and 18 and 2,000 μm diameter (Figure 5). 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).

Although we are aware that the number of snow and stream samples collected is relatively small, we note first that these unique preliminary samples were incredibly difficult to collect.

**Figure 2. Collection of the Highest Known MP Sample on Mt. Everest Balcony**

High-elevation climbers and Sherpa wearing "Himalayan suits" made of waterproof acrylic fibers at the Balcony (~8,440 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).

Shipping constraints required that the pre-cleaned 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 analyzed 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 MPs are significantly abundant in this region to necessitate additional and comprehensive further study. However, it should be noted that no field blanks were collected, and therefore the results are as representative as possible given this omission in sampling detail.

## DISCUSSION

Our research reports an important initial assessment of MP contamination on Mt. Everest, with an estimated 30 MP $L^{-1}$ in snow and significantly fewer MPs in the stream samples. This might be due to the stream constantly moving and having greater dilution from the melting glaciers versus the more static snow. Additionally, the quantity of stream water collected is substantially less than what is typically analyzed by other studies because of the logistical limitations, which might have also impacted the stream sample results.[26–28]

In the atmosphere, snow binds to particles and pollutants, which are eventually deposited on Earth's surfaces; a phenomenon termed "scavenging."[43] Bergmann et al.[44] found that the MP concentration of Arctic snow was significantly lower (0–14,400 MP $L^{-1}$) than in European snow (190–154,000 MP $L^{-1}$). However, MP detected in snow samples from the Swiss Alps were more similar to our results at 190 MP $L^{-1}$ and suggest that altitude, and/or prevalence of tourism might affect MP concentration.[44] Additionally, the minimum size observed in our research was 36 μm; it is expected that smaller particles might have been present but were below the minimum particle size of this study.

Previous research by Dris et al. (2015) found 29–280 MP $m^{-2}$ $day^{-1}$ from atmospheric fallout in Paris, France.[45] More than 90% of MPs observed were fibers, which is consistent with our results showing dominantly fibrous MPs. Similar work by Wright et al.[46] 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%). Allen et al. also analyzed atmospheric MP deposition in a remote, pristine mountain catchment in the French Pyrenees.[31] 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 was from 5,776 m.a.s.l., from a glacier lake below Mt. Shishapangma in Tibet; that snow sample contained ~22 MP $L^{-1}$, including red, black, and blue fibers.[47]

Mt. Everest is located far away from major populations or industrial centers 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, compared with those in other areas, MP concentrations were at higher levels in snow samples taken 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 including 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.

In our research, the majority of MPs detected were fibrous, and their size ranged between 36 and 3,800 μm in length. Subsequently, it is highly suspected that these MPs originated from performance clothing and equipment used by climbers and trekkers rather than existing macroplastic debris. Previous research has estimated that 1 billion MPs could be released from a person wearing 1 kg (e.g., a coat) of polyester clothing per year, equating to 2.8 million MPs released per day.[30] 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; Table S2). These polymer types are used to make the majority of outdoor gear, where polyester, acrylic, and polypropylene are standard fibers for clothing.[48] Polyester and nylon are also popular materials for tents and climbing ropes. This material is flexible, durable, and can be modified for outdoor use with other chemicals (i.e., incorporating water resistance). The rise in the use of outdoor clothing and gear made from plastic within the last decade (examples given in Figure 6) will have had an impact on MP accumulation over this period.

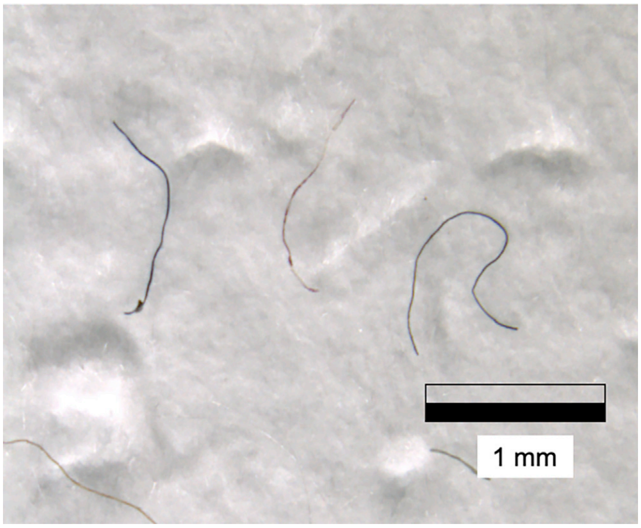


**Figure 3. Mt. Everest MP Fibers**

A selection of microfibers found in snow samples from Mt. Everest Balcony (8,440 m), which are consistent with fibers from outdoor clothing.

Additionally, the wind might transport 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.[49] Air mass trajectories have also previously suggested that MP had transported over a distance up to 95 km.[31] Brahney et al.[32] 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. Windblown MPs are increasingly possible in this region, given that the Mt. Everest often sees prolonged strong winds, especially on its upper reaches.[50] However, this might also mean that deposited microplastics on Mt. Everest are subsequently blown further away.

Although 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,[50] 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.[51] 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[2,52,53] or those residing further downstream, though we note again lack of field blank might reduce the robustness of our results. Additionally, the processes differentiating snow and water MP concentrations remain elusive. If MPs preferentially remain on snow-covered glaciers, then the increasingly high rate of melting glaciers in high mountains in Asia[54] could result in increasing MPs found in the downstream meltwater as glaciers recede. Although 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 needed 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 recently launched debris removal operations.[55] In 2019, the Nepalese Army cleared about 10,000 kg of waste from the region.[56] 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 $4,000 deposit, which is returned if they bring their waste back down with them.[56] They have also banned single-use plastics in the region from January 2020 in a bid to cut down on waste left by climbers.[57] Further solutions for addressing plastic pollution will require choices in environmental options from industry and coordinated actions across a number of sectors and stakeholders.[39]

Analyzing the quantity of microplastic in remote areas, such as Mt. Everest, helps us to identify how polluted these areas are becoming from human activities. 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 properly disposed.[52] However, MPs are just as persistent and typically more difficult to remove, but often not considered due to being less visible. An important finding in this study is that the MPs are primarily polyester fibers, primarily used (in the Mt. Everest environment) in clothing, rope, flags, and tents. 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 focused 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 MPs. For example, it has been suggested by Napper et al.[45] that reducing shedding through changes in fabric design could be an effective overarching mitigation strategy, given that this is likely to help reduce emissions during all use phases: wearing, washing, and tumble drying.[30,48,58] 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 microfibers accumulating in the environment is currently unclear.[59] It would be useful to engage the manufacturers of performance clothing and equipment used by climbers and trekkers in a dialog to explore how these findings could be considered in design and development, especially because many of these companies have active environmental stewardship agendas.

## CONCLUSIONS

MP contamination has been found from the bottom of the sea[60] to near the top of the world's highest mountain, according to our

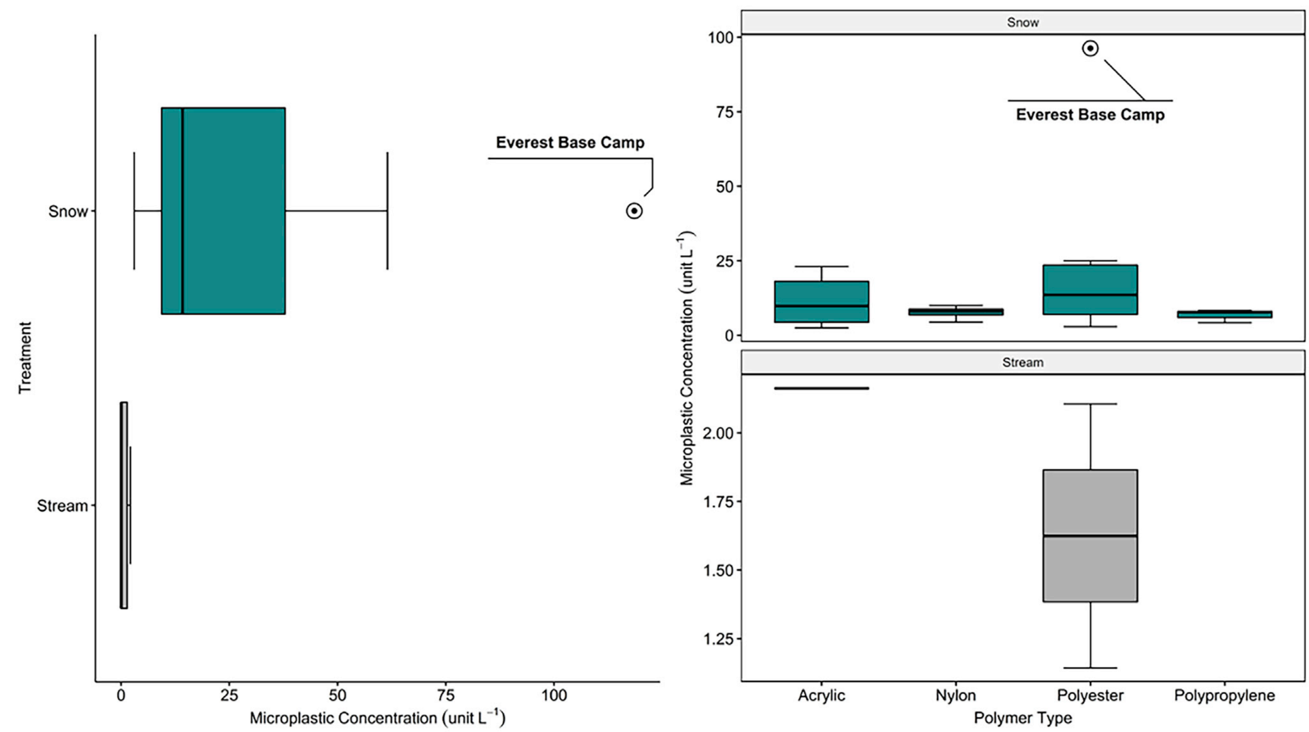


**Figure 4. Concentration and Polymer Type of Microplastics on Mt. Everest**

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

new results, highlighting the extent of global plastic pollution across the remote environments. Despite Mt. Everest's high altitude and location away from major population centers, this study reports the highest altitude MP ever recorded. 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 MPs are ubiquitous throughout most environments, so now we must focus on robust evidence to inform appropriate solutions.

## EXPERIMENTAL PROCEDURES

### Resource Availability

#### *Lead Contact*

Further information and requests for resources and reagents should be directed to and will be fulfilled by the Lead Contact, Imogen Napper (imogen.napper@plymouth.ac.uk).

#### *Materials Availability*

There are restrictions to the availability of the MPs for further analyses because relatively few MPs were collected; however, they will be made available on request to the best of our ability.

#### *Data and Code Availability*

The original data generated during this study are available at Mendeley Data, https://doi.org/10.17632/ggk9yhc5vc.1.

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 microfiber filter papers. In order to minimize plastic contamination, all samples were taken into the wind 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.). Unfortunately, no field blanks were collected, which decreases the robustness of our study.

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 in order to measure only recent deposition.

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 and near the location of a high-elevation camp (Figure 6). Our highest sample (~8,440 m.a.s.l.) was collected from ~50 m above the Balcony, where

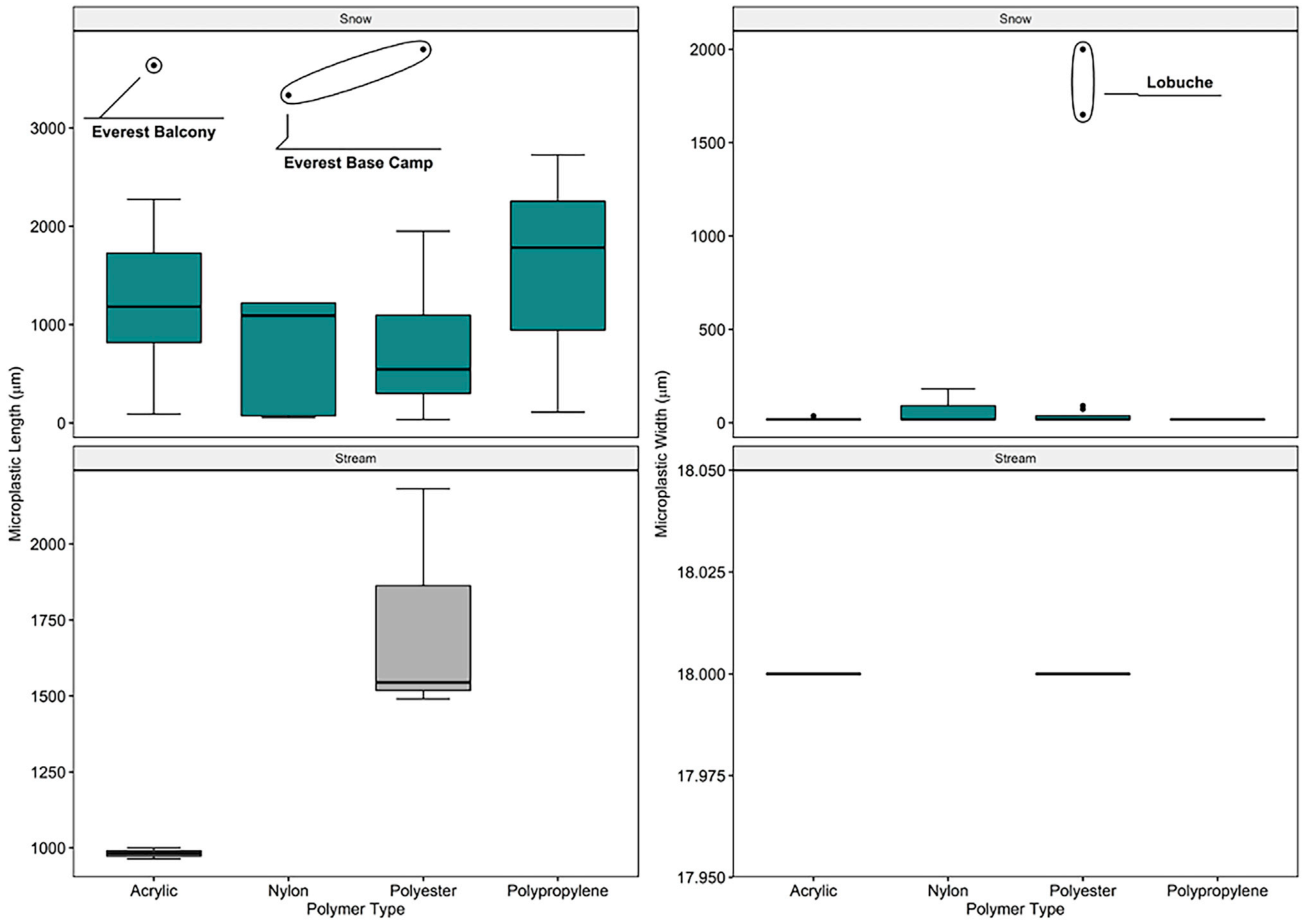


**Figure 5. Characteristics of Mt. Everest Microplastics**

Boxplots showing the microplastic dimensions in micrometres—(A) length, left and (B) width, right—of polymer types across snow and stream samples. The majority of microplastics found were microfibers.

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.

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.

Older 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, no more than 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.

The collected samples represent an exciting range of sample types, which were collected over a single season in the Khumbu Region. The requirements of shipping, and size and weight of the sampling containers all resulted in significant limitations to the ability to collect more varied samples or more duplicate samples. Further, our samples were collected during a single pre-monsoon season in 2019 and therefore seasonal deposition of either local or distal MP pollution are not discernible. The results of the preliminary study are as robust as possible within the study limitations, including the lack of field blank, and show significant MP in environment of the Mt. Everest Region, which is worthy of further assessment.

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

**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).

microfiber filter papers and the filtered volume recorded. The filter papers were examined using a S9E - Leica light microscope and no MPs were removed before microscopic analysis. Information on the types of MP were annotated, according to the definition of a fiber as having a length of at least 20 times the width. Dimensions by graticule measuring (length and diameter), and color were also recorded (see Table 1; Table S1; Table S2).

All suspected MPs (minimum particle size was > 30 μm) were removed from the filter paper and separated into glass Petri dishes. The MPs were then 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 fibers ATR) to identify MP type.

For Quality Assurance and Quality Control, during any laboratory analysis, all steps were conducted in a purpose-built microplastics clean laboratory; which had a positive pressure air system, limited and controlled access, and procedural blanks (2 blanks for every sample during filtration and analysis). 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. However, like sample analysis, due to the minimum particle size being > 30 μm, smaller MP may have been missed as not visible and therefore not quantified.

The number of MP in each sample was calculated per liter, so that the volume was standardized. A general linear model was carried out to assess the difference in the MP abundance in samples taken from different sample types (snow or stream). To fit the assumptions of the model, a quasi-poisson distribution was used.[61] To assess the model fit, sample against residual and quartile-quartile plots were visually inspected. The same methodology was also applied for analyzing 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.[62]

## SUPPLEMENTAL INFORMATION

Supplemental Information can be found online at https://doi.org/10.1016/j.oneear.2020.10.020.

## ACKNOWLEDGMENTS

This research was conducted in partnership with the National Geographic Society, Rolex, and Tribhuvan University, with approval from all relevant agencies of the Government of Nepal. We also wish to thank the communities of the Khumbu Region, our climbing support team, and Shangri-La Nepal Trek. The authors would also like to thank all those who helped on the 2019 National Geographic and Rolex Perpetual Planet Everest Expedition and also the technicians from the Marine Biology and Ecology Research Centre (MBERC). We also thank A.M. Tait and S.W. Guilford for generation of the sample location figure and T. Maddalene and J. Jambeck for helpful discussions. We would also like to thank the editor and two anonymous reviewers for helping to improve the manuscript prior to publication. This work was supported by National Geographic Society and Rolex.

## AUTHOR CONTRIBUTIONS

Conceptualization, I.E.N., H.J.K., and R.C.T.; Methodology, I.E.N., H.J.K., and R.C.T.; Investigation, H.C., S.E., P.A.M., M.P., A.C.E., and A.P.G.; Formal Analysis, B.F.R.D. and I.E.N.; Data Curation, B.F.R.D. and I.E.N.; Writing – Original Draft, I.E.N.; Writing – Review & Editing, I.E.N., B.F.R.D., H.C., S.E., H.J.K, P.A.M., K.R.M., M.P., A.C.E., A.P.G., and R.C.T.; Resources, A.C.E. and S.E.; Supervision, R.C.T.

## DECLARATION OF INTERESTS

The authors declare no conflict of interest.

Received: July 19, 2020
Revised: September 7, 2020
Accepted: October 28, 2020
Published: November 20, 2020

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