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Unveiling microplastics pollution in Alaskan waters and snow†

Subhabrata Dev, *[ab] Davis Schwarz,[bc] Muradur Rashedin,[bc] Md Ibnul Hasan, [bc] Darya Kholodova,[bc] Shane Billings,[b] David L. Barnes,[bd] Nicole Misarti, [b] Navid B. Saleh [e] and Srijan Aggarwal *[bc]

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While microplastics (MPs) are globally prevalent in marine environments, extending to the Arctic and sub-Arctic regions, the extent and distribution of MPs in terrestrial waters, drinking water sources, and recreational water in these areas remain unknown. This field study establishes a baseline for MPs in surface water sources, including lakes, rivers, and creeks, as well as in snow across three geo-locations (*i.e.*, Far North, Interior, and Southcentral) in Alaska. Results (mean ± SE) show that the highest MP counts exist in snow (681 ± 45 L^{-1}), followed by lakes (361 ± 76 L^{-1}), creeks (377 ± 88 L^{-1}), and rivers (359 ± 106 L^{-1}). The smallest MPs (*i.e.*, 90.6 ± 4 μm) also happened to have occurred in snow, followed by their larger sizes in lakes (203.9 ± 65 μm), creeks (382.8 ± 136.5 μm), and rivers (455.4 ± 212 μm). The physical morphology of MPs varies widely. MP fragments are predominant (*i.e.*, nearly 62–74%) in these sites, while MP fibers (nearly 13–21%), pellets (nearly 13–18%), and films (<6%) also exist in appreciable quantities. Geolocation-wise, the Far North, where MPs were collected from off-road locations, shows the highest MP counts (695 ± 58 L^{-1}), compared to Interior (473 ± 64 L^{-1}) and Southcentral (447 ± 62 L^{-1}) Alaska. Results also indicate that the occurrence of MPs in the source waters and snow decreases with increasing distance from the nearest coastlines and towns or communities. These baseline observations of MPs in terrestrial waters and precipitation across Alaska indicate MP pollution even in less-explored environments. This can be seen as a cause for concern with regard to MP exposure and risks in the region and beyond.

Water impact

Microplastics contamination of pristine water resources in Alaska, which sustain diverse indigenous tribes and rural communities lacking adequate water treatment infrastructure, remains poorly understood. We provide source-water specific baseline data for microplastics counts, size, and morphology from samples collected across Alaska. This data would be useful for formulating prospective risk assessment and mitigation strategies for Alaska and other remote regions.

1. Introduction

Since the advent of plastics in the 1950s, the plastics industry has seen tremendous growth, with an aggregate production to date nearing 10 billion metric tons and an annual production reaching nearly 400 million metric tons in 2021.[1,2] Only about 21% of the plastics produced have been incinerated or recycled, with the remainder being released into the environment or accumulated in landfill sites.[2] Plastics released into the environment break down into smaller fragments and fibers due to natural weathering (*e.g.*, ultraviolet radiation, abrasion), forming 'microplastics (MPs)' – typically defined as particles less than 5 mm in size. These plastics can further break down into smaller sizes (*i.e.*, nanoplastics sized at <1 μm), which then can essentially become a part of the hydrological cycle and be subject to atmospheric transport. Not surprisingly, MPs have been found throughout the world, from the deepest oceans[3] to the highest peaks.[4,5] However, very few studies on MP atmospheric prevalence and deposition have been conducted in areas less impacted by human activities. The recent reports of MP occurrences in remote locations, *i.e.*, from the French Pyrenees Mountains to remote Mongolian lakes, raise concern.

[a] *Department of Civil Engineering, University of Alaska Anchorage, Anchorage, Alaska 99508, USA*
[b] *Water and Environmental Research Center, University of Alaska Fairbanks, Fairbanks, Alaska 99775, USA. E-mail: sdev@alaska.edu*
[c] *Department of Civil, Geological, and Environmental Engineering, University of Alaska Fairbanks, Fairbanks, Alaska, 99775, USA. E-mail: saggarwal@alaska.edu*
[d] *Department of Civil Engineering, Montana State University, Bozeman, Montana 59717, USA*
[e] *Fariborz Maseeh Department of Civil, Architectural and Environmental Engineering, University of Texas at Austin, Austin, Texas 78712, USA*

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There is an acute need to assess the extent of MP pollution in the environment, particularly in desolate locations, to quantify 'background' MP levels and adequately project its deleterious impacts on humans and the broader biosphere.

Detecting MPs in the ostensibly "pristine" landscapes of Alaska holds significance not only for human health but also for the well-being of numerous endangered species crucial to maintaining ecological balance. In Alaska, prolonged freezing temperatures (*i.e.*, six to nine months per year), presence of permafrost, seasonal snow, and ice cover create unique challenges for the locals to have a continuous and safe water supply. Many who live in smaller remote communities, *i.e.*, are "off the (water) grid", collect rainwater and/or snow for drinking. Some use snow fences to harvest snow for their fresh water supply. If MPs end up in precipitation (*i.e.*, in rainfall and snow), these will likely have a direct impact on human health. It is well established that MPs pose various health risks, including impacts on the immune system,[6] cellular metabolism,[7] and blood circulatory system,[8,9] and they also lead to neurotoxicity.[10] Additionally, many Indigenous Alaskan tribes rely on fishing and hunting birds and marine animals for subsistence living and as key economic activities in the state. Fish uptake MPs from surface waters and impact the food chain.[11,12] A recent study by the University of Alaska Fairbanks showed that seals from Far North regions of Alaska contain MPs in their gut.[13] Similarly, various sea birds in Alaska are found to contain MPs in their tissues.[14] Thus, understanding the prevalence and distribution of MPs in surface waters and snow across Alaska is important to assess potential human and ecological risks from MPs.

Transport of MPs in rivers, lakes, and oceans has been extensively studied.[15–21] Some research has been conducted in urban areas showing an atmospheric transmission of MPs over a short distance.[22–24] However, it has been believed that MPs can travel at least 100 km from their source, based on a field study conducted in the underpopulated areas of the Pyrenees Mountains.[4] Wetherbee *et al.*[5] have found MPs in precipitation in the remote areas of the Rockies, while Free *et al.*[25] have shown MPs in a remote lake in Mongolia. Consequently, it is reasonable to anticipate that MPs might be present in the natural waters of Alaska, frequently characterized as the northernmost 'last frontier' of the United States. Alaska is situated within the Arctic and sub-Arctic regions and is commonly perceived as environmentally pristine due to its remote location and sparse population. A recent study shows the presence of MPs in rainwater, snow, and glacier meltwater in Southeast Alaska.[26] To-date, there is no comprehensive assessment of microplastic contamination in terrestrial waters across Alaska.

This study aims to determine MP concentrations in surface waters and snow samples collected from three regions in Alaska, *i.e.*, Far North, Interior, and Southcentral Alaska. It is hypothesized that the count, size, and morphology of MPs in surface waters and snow will differ based on geo-locations. The research team collected samples from terrestrial snow and water sources, such as lakes, rivers, and creeks, over a year-long field sampling campaign. They used fluorescent Nile Red dye and fluorescence microscopy to determine the number, size, and morphology of MPs. Comprehensive statistical analyses were conducted, including principal component analysis (PCA), to assess the number and size variations between sources and the correlation of MP counts with location, elevation, and distance from the sampling points. Results from this study confirm the presence of MPs in these Arctic environments and establish a baseline for assessing MP prevalence in this region.

2. Materials & methods

2.1 Study area

A comprehensive assessment of the geographic variability and dissemination of MPs in Alaska necessitates the thorough collection of spatial samples from diverse sources, including surface water and atmospheric precipitation, across the state. Alaska, which is surrounded by sea on three sides, is divided into five major regions: Far North, Interior, Southcentral, Southwest, and Southeast (Fig. 1). The Far North, Interior, and Southcentral regions were chosen due to their high population density and accessibility. Sampling included rivers, creeks, and lakes in the Interior and Southcentral regions, as well as snow samples from remote locations in both the Interior and Far North regions. The Far North, predominantly remote, hosts rural/Indigenous communities inaccessible by road. In contrast, the Interior and Southcentral regions, comprising towns and cities, are largely accessible by road. Water bodies on the state road system, heavily used for fishing and recreation, were selected for sampling.

2.2 Sample collection

From March 2020 to July 2021, we collected 73 samples from rivers (12), lakes (12), creeks (13), and snow (36) (Fig. 1). Lake, river, and creek samples were collected from the surface during summer months (June–August), and the snow samples were collected during spring (March–April). Sample metadata consisting of sampling point coordinates, sampling dates, location, and source are provided in Table S1.† Samples were collected and transported in glass (1 L) and high-density polyethylene (HDPE) containers (500 mL), and later stored in a sample storage facility at the Joseph E. Usibelli Engineering Learning and Innovation Building at the University of Alaska Fairbanks for further analyses.

2.3 MP count, size, and shape determination

Based on prior reports,[27–32] we adapted a fluorescence microscopy-based method for the quantification and morphological analyses of microplastics. The details of the method are presented in the ESI† (Section S1). Briefly, to prepare each sample, 100 mL sample was transferred into a 250 mL conical flask. 1 mL Nile Red dye from a concentrated stock (with 10 μg mL^{-1}) was added to the flask. The mixture was incubated

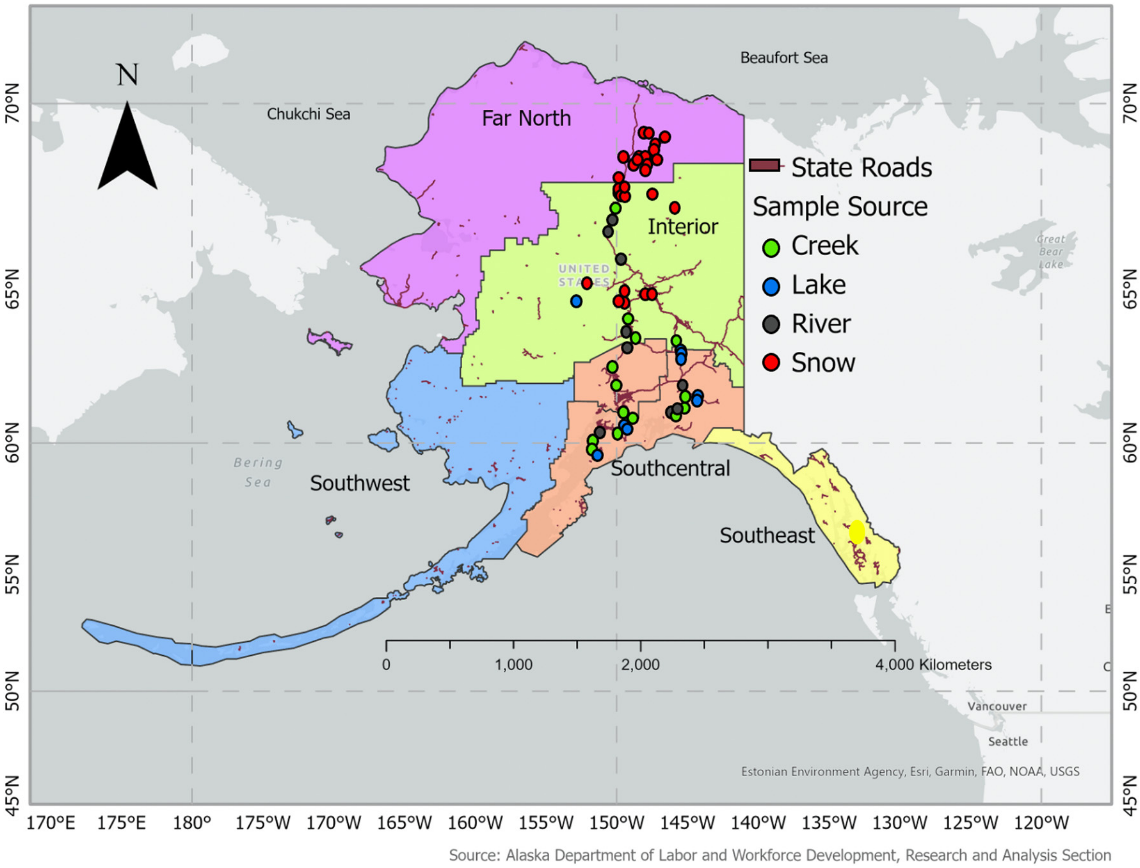

Fig. 1 The study area map showing sample locations from different regions of Alaska (Southcentral, Interior, and Far North) where surface waters and snow samples were collected for this study.

at room temperature for one hour (Fig. S1†). The mixture was then transferred to a 250 mL HDPE bottle, 0.136 g $ZnCl_2$ was added, and the solution was centrifuged at 3400 rpm for 10 minutes to separate MPs. The supernatant containing MPs was decanted into a 250 mL conical flask, H_2O_2 at 1:1 ratio was added, and the mixture was incubated at 70 °C for 3 hours. Once cooled to room temperature, the incubated sample was vacuum filtered using a 47 mm glass fiber (GF) filter paper (0.45 μm). The GF filter was then transferred to a petri dish and viewed under a fluorescence microscope (FM820T-14M3, OMAX) at 400× magnification in a dark room. Images of each microscopic fields were captured with an 18-megapixel camera (A35180U3, OMAX). The morphology of the MPs was also evaluated using the collected images (Fig. S2†). Long filamentous MP segments were classified as 'fibers'. Irregular shaped short particles derived from isolated parts of large plastic debris were considered as 'fragments'. MPs appearing spherical in shape or layered were classified as 'pellets' or 'films', respectively (Fig. S2†). The size of MPs was measured using the line tool in the image analysis program, ImageJ.[33]

2.4 Quality control and assurance

Seven deionized water samples (with 18.2 MΩ cm conductivity), collected from an ultrapure water purification system (D11911, Barnstead), were placed in 500 mL HDPE bottles and served as control blanks. All the blanks were stored, processed, and analyzed for MPs using the same procedures and protocols that were used for the field samples. Sample preparation and MP analyses were conducted at Joseph E. Usibelli Engineering Learning and Innovation Building at the University of Alaska Fairbanks campus, which is equipped with heat recovery ventilation (HRV) systems outfitted with filters rated to remove particles >1 μm, thereby minimizing the indoor air particulate interference in the analysis. The MP counts from the blank samples were used for calculating mean, standard deviation, limit of detection (LOD), and limit of quantification (LOQ) as recommended by the Association of Official Analytical Chemists (AOCC) Internationals[34] and several other studies.[35–37] The LOD was defined as 3.3 × SD and LOQ as 10 × SD.[35,36] The MP counts were blank subtracted, and the left-censored data (values below LOD and LOQ) were substituted by LOD/2 (for <LOD values) and LOQ/2 (for detectable values below LOQ) for statistical comparisons and analyses.

2.5 Statistical analysis

A comprehensive statistical analysis was conducted using R Studio (version 4.3.1). The distribution of MP counts (particles per L) and MP morphology (%) from different sources and regions were analyzed for normality using the Shapiro–Wilk test. The distribution of MP size (μm) was analyzed using Kolmogorov–Smirnov test. The comparison of MP count in different sources and regions was performed using the Kruskal–Wallis and pairwise Wilcoxon tests. The MP morphology was compared with the Mann–Whitney test. The correlation of MP sources with elevation and distance of sampling location from the nearest town (distance to town; DTT), coast (distance to coast; DTC), and highway (distance to highway; DTH) was investigated by principal component analysis (PCA). The PCA analysis was performed by using the 'prcomp' function of psych package in R (**https://cran.r-project.org/web/packages/psych/**), and the results were plotted using the ggbiplot package in R (**https://github.com/vqv/ggbiplot**). Finally, the 'PCAtest' function within the PCAtest package (**https://github.com/arleyc/PCAtest**) was used to test the statistical significance of the PCA. The R studio code for PCA analysis is presented in the ESI† (Section S2).

3. Results and discussion

3.1 Microplastics count and size

The complete dataset with MP size and counts for all samples has been deposited in NCEI (National Centers for Environmental Information) geoportal (**https://www.ncei.noaa.gov/metadata/geoportal/**) public database (accession no. 0288866). The LOD and LOQ for the MP analysis method are presented in Table S2.† Snow samples exhibit the highest MP count (681 ± 45 L^{-1}; mean ± SE), whereas the mean counts in creek (377 ± 88 L^{-1}), river (359 ± 106 L^{-1}), and lake (361 ± 76 L^{-1}) samples range below LOQ. The variation of MPs count between sources is presented in Fig. 2. Distribution of MP data for count (L^{-1}), size (μm), and morphology (%) is presented in Table S3.† MP counts vary substantially among the source types ($p = 9.1 \times 10^{-4}$, Kruskal–Wallis). Fig. 2 shows that MP counts in snow are significantly higher than those in other types ($p < 0.05$). No significant differences in MP counts were noted between the lake, creek, and river water samples ($p > 0.05$). The size of MPs (mean ± SE) varies between sample types (Fig. 3) with the least MP size observed in snow (90.6 ± 4 μm), followed by lake (203.9 ± 65 μm), (455.5 ± 212 μm), creek (382.8 ± 136.5 μm), and river (455.5 ± 212 μm) samples. Kruskal–Wallis test shows a significant difference in mean MP size for MPs from different source types (p-value = 2×10^{-16}). Subsequently, two-sample Mann–Whitney test comparing the sources shows that the mean MP size in snow is significantly lower than in other source samples, except for the river water ($p = 0.78$) (Table 1). The MP size for lake samples is significantly lower than those from river samples ($p = 5.3 \times 10^{-5}$) but not different than MP size for creek water samples ($p = 0.13$). MP size for creek samples is significantly different from MP size for the river samples ($p = 2.2 \times 10^{-6}$).

The higher MP counts in snow can be attributed to their lower particle sizes (Fig. 2 and 3). As the MPs decrease in size, they tend to have lower mass and are rather easily suspended in the air and transported in the atmosphere.[22,38] This can result in higher particle counts in snow,[39–41] even in remote and otherwise pristine locations.[38] In the dataset reported here, most of the snow samples were collected from remote locations in the Interior and Far North regions in Alaska. The average MP counts (681 ± 44 L^{-1}) in these snow samples is 24–300 times higher than those found in similar remote regions across the globe, *e.g.*, as observed by Aves *et al.* in Antarctica for the first time.[42] Similar observations have been made in remote Arctic regions, including Nunavut in Canada[43] and Western Italian Alps,[39] and some regions in Asia, including Mt. Everest[44] and the inner Mongolian plateau.[40] The average size of snow MPs reported here, however, is comparable to those found in remote Swiss Alps,[45] but is 1/200th of those found in Vatnajökull ice cap in Iceland[46] and Mt. Everest.[44] The presence of MPs in snow could be attributed to precipitation, atmospheric transport from vehicular traffic,[47] landfills,[40,48] and coastal petroleum extraction.[49,50]

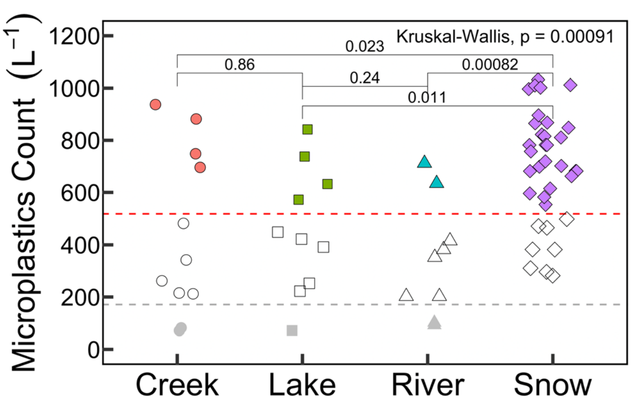

Fig. 2 Distribution of MP counts in creek, lake, river, and snow samples across Alaska. The counts below red and grey discontinuous lines present MP counts below LOQ and LOD, respectively. p values of < 0.05 show a significant difference in MP counts between sources.

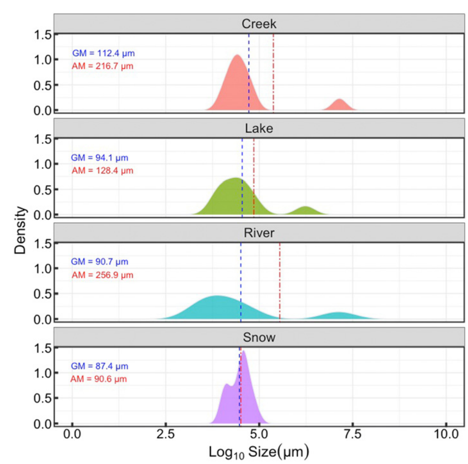

Fig. 3 Kernel density plots showing the size distribution of MPs for different source waters. GM (geometric mean) is shown in red, and AM (arithmetic mean) is shown in blue.

Table 1 Pairwise Wilcoxon tests for comparison of various microplastics data. The P values in bold font show a significant difference between two groups ($P < 0.05$)

Data type	Source		P value
MPs size (μm)	Snow *vs.* Lake		$\mathbf{1.4 \times 10^{-9}}$
	Snow *vs.* creek		$\mathbf{9.8 \times 10^{-13}}$
	Snow *vs.* river		0.78
	Lake *vs.* creek		0.13
	Lake *vs.* river		$\mathbf{5.3 \times 10^{-5}}$
	Creek *vs.* river		$\mathbf{2.2 \times 10^{-6}}$
MPs morphology percentage (%)	Fiber	Lake *vs.* river	0.91
		Lake *vs.* creek	0.35
		Lake *vs.* snow	0.98
		River *vs.* creek	0.45
		River *vs.* snow	0.93
		Creek *vs.* snow	0.15
		Lake *vs.* river	0.75
		Lake *vs.* creek	0.31
		Lake *vs.* snow	0.68
		River *vs.* creek	0.45
		River *vs.* snow	0.45
		Creek *vs.* snow	0.07
	Pellet	Lake *vs.* river	0.55
		Lake *vs.* creek	0.90
		Lake *vs.* snow	0.53
		River *vs.* creek	0.69
		River *vs.* snow	0.05
		Creek *vs.* snow	0.42
	Film	Lake *vs.* river	0.91
		Lake *vs.* creek	1
		Lake *vs.* snow	0.39
		River *vs.* creek	0.92
		River *vs.* snow	0.66
		Creek *vs.* snow	0.28

The surface water systems sampled in this study are adjacent to a highway and thus likely to receive MPs from vehicular traffic tire wear. Interestingly, for the surface water samples, there is no significant difference ($P > 0.05$) in MP counts among different source water types (*i.e.*, lakes, rivers, and creeks; Fig. 2, Table 1), possibly because of the dominance of tire wear particle intrusion from the highways.[51,52] Highway runoff can also produce fragments from wearing the polymer embedded in polymer-modified asphalts.[53,54] Alaskan pavements are often prepared with asphalts modified with styrene–butadiene–styrene, which commonly show low-temperature cracking.[55,56] At lower temperatures (*e.g.*, high rate of decay at 5 °C (ref. 54 and 57)), common in Alaskan winters, decay of polymer-modified asphalts occurs. The reports of tire and pavement wear particles' presence in the aquatic environment in Alaska[53,58–60] are consistent with the unique climatic conditions of the region and our findings herein.

The MPs found in some of the Alaskan freshwater sources are much higher in amount as compared to other remote freshwaters across the globe, such as the lakes located in Switzerland[61] and Kola peninsula in northwest Russia,[62] but lower than the rivers located in the Qinghai-Tibet plateau in China that serve as the headstream for many freshwater bodies in Asia.[63] Most rivers we studied here are glacier-fed and receive MPs from glacial and snow meltwaters. Thus, the MP size distribution in rivers is not uniquely different from snow. Various glaciers around the world, including those in the Italian Alps,[64] Vatnajökull ice cap in Iceland,[65] and Khumbu glacier in Nepal (near Mt. Everest)[44] contain MP particles and have been known to release these with the meltwater into receiving riverine systems. Lakes and creeks in our study do not show significant differences in MP size distribution, possibly because they receive MPs from similar sources, including highways and weathered plastics.

3.2 Microplastics morphology

We categorized MPs into four broad morphological categories: fibers, fragments, pellets, and films (Fig. S2†). Fragments are the dominant MP type, contributing to almost 65–75% of total MPs in all the samples (Fig. 4). Highest percentage of fragments are recorded in the snow samples (~74%), while the fragment percentage in rivers, creeks, and lakes are similar (62–65%). Particles with film morphology constitute the lowest percentage of MPs in all samples, contributing to <6% of the total MP count. Fibers and pellets are similar, *i.e.*, 13–21% and 13–18%, respectively. The percentage of pellets in snow samples is below 7%, whereas in lakes, rivers, and creeks, the pellet contribution is slightly higher, amounting to 13–18%.

Most of the MPs in all the studied source waters were classified as fragments (*i.e.*, 65–75%), followed by fibers. It has been previously reported that tire and pavement surface wear serve as a major contributor to fragmented MP generation.[53,58–60] Similarly, degradation products of larger plastic wastes also contribute to the fragment MP particles.[66,67] Temperatures below freezing during the winter season in Alaska may likely make the larger plastic wastes brittle, promoting their decay to generate MP fragments.[68] The fibers are attributed primarily to fishing equipment,[69] clothing articles,[70,71] laundry effluent,[71] and domestic and textile wastewater effluents.[72–74] Pellet MPs are primarily sourced from plastic manufacturing industries, microbeads, personal care products, and wastewater effluents.[75–77]

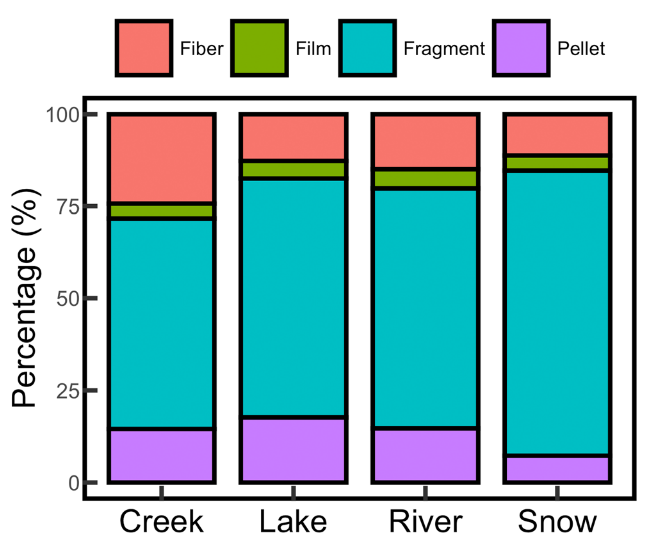

Fig. 4 Percentage of MPs morphological types in different source waters.

The high relative abundance of fragment MPs, as observed in this study, is consistent with earlier reports on Lake Hovsgol in northern Mongolia (40%),[25] Xiang Jiang river near Changsha city in China (40–60%),[78] remote high mountain lakes in Spain (~60%),[79] atmospheric samples from Hamburg metropolitan area in Germany (88–97%),[80] and surface water samples collected from the Great Lakes of North America (~70%).[76] Contrasting results have been reported in other studies where an abundance of fibers in freshwater samples was reported.[81–84] A higher percentage of fibers in freshwater indicates MP contamination from domestic wastewater, personal care products, fishing gear, and plastic manufacturing industries.[77,85] The lower percentage of fibers and fragments in the water samples in this study indicates possible lower impacts of wastewater effluents, textiles, and plastic manufacturing on the Alaskan surface waters, which is in line with the remote and uninhabited sample collection locales. Although fishing is a major activity in Alaska, the lower fiber percentage indicates lower recreational use of water sources sampled and thus reduces the impact of fishing on the MP contamination for the collected samples.

3.3 Spatial distribution of MPs

The regional distribution of MP counts across Alaska is presented in Fig. 5. The average MP counts in Southcentral, Interior, and Far North are 447 ± 62, 473 ± 64, and 695 ± 58 L^{-1}, respectively. We observe no significant difference in MP counts between the Southcentral and Interior samples (yielding a p-value of 0.58). Also, we note significant differences in MP counts between samples from the Southcentral and Far North regions ($p = 7.4 \times 10^{-3}$) and between the Interior and Far North regions ($p = 0.047$). We also assessed the changes in MP counts based on the distance of sampling locations from the nearest coast or nearest town (Fig. 6). Results show that the MP counts correlate negatively with distance from the nearest coast or town for river and creek samples. It should also be noted, however, that no clear trend exists between MP counts and distance to nearest coast or town when particles from all sources are considered together (Fig. S5†). Higher MP counts in samples from rivers and creeks collected near a town may be influenced by anthropogenic activities and, thus, the release of MPs into these waterbodies. The majority of population in Alaska lives in two cities: Anchorage (289 810) in the Southcentral and Fairbanks (96 747) in the Interior region, whereas Far North is least populated and comprises three boroughs: Nome, North Slope, and Northwest Arctic Borough with 10–12 rural communities totaling a population of approximately 27 432 according to 2019 census data.[86–89] Although Far North region is less populated, the higher MP counts measured here may be attributed to the larger proportion of snow samples, which likely contain atmospherically transported MPs from distant areas. Results from principal component analysis (PCA) reveal that snow samples are different and independent from other sample types (Fig. 7A). The first two principal component axes (PC1 and PC2) are significant and account for 62% of the variance. DTT, DTC, and Longitude seem to be well correlated. Also, DTT and DTC directions in the Fig. 7 biplots are almost at a right angle to MPC, which indicates no correlation between MP counts and distances to towns and coasts. This aligns with the lack of any correlation for overall MP counts with DTT and DTC (Fig. S5†) and further drives the premise that the MPs measured in this work are primarily sourced from precipitation or atmospheric transport. MPC and DTH are positively correlated, indicating that MP counts increase with distance to the highway. This may be explained by the fact that most of the snow samples that dominated the MP counts were collected further away from the highway. Also, from Fig. 7A, MPC and DTH are positively correlated with snow samples, implying that snow has higher MP counts as seen in Fig. 2. Additionally, Fig. 7B presents a strong correlation between Far North samples and MPC, indicating that samples from the Far North region have highest MP counts, which is evident from Fig. 5.

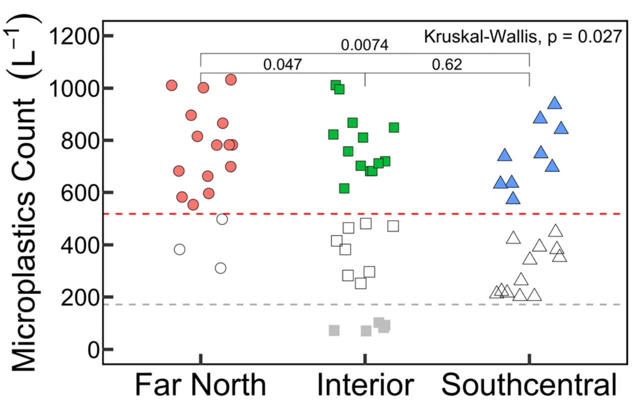

Fig. 5 Distributions of MP count in three different regions of Alaska. The counts below red and grey discontinuous lines present MP counts below LOQ and LOD, respectively. A p-value of < 0.05 shows a significant difference in MP counts between sources.

Decreasing MP counts with increasing distance from the coast for river and creek samples (Fig. 6A) indicates a possible impact of the ocean, where MPs from wave-generated foam can become airborne and undergo atmospheric transport.[90,91] Oceans have been reported to contribute 11% of the atmospheric MPs in the western United States.[92] Therefore, atmospheric transportation of MPs from the Gulf of Alaska may serve as an additional contributing factor for MP proliferation in terrestrial water sources, especially in coastal and near-shore regions, including Southcentral Alaska. Lake samples show a positive correlation for MP counts with the distance from the nearest coast or town. Most lakes sampled here are within 100 km of a coast or a town and are accessible by road. Thus, MP counts in these lakes may be impacted by additional factors, including atmospheric transport from nearby cities, roadways, or highway runoff. Therefore, distance from the nearest coast or towns may not necessarily exhibit a decreasing trend in MP contamination in the Alaskan lakes sampled here. Although we observed a correlation of MP counts with distance for all source types (Fig. 6), it should be noted that

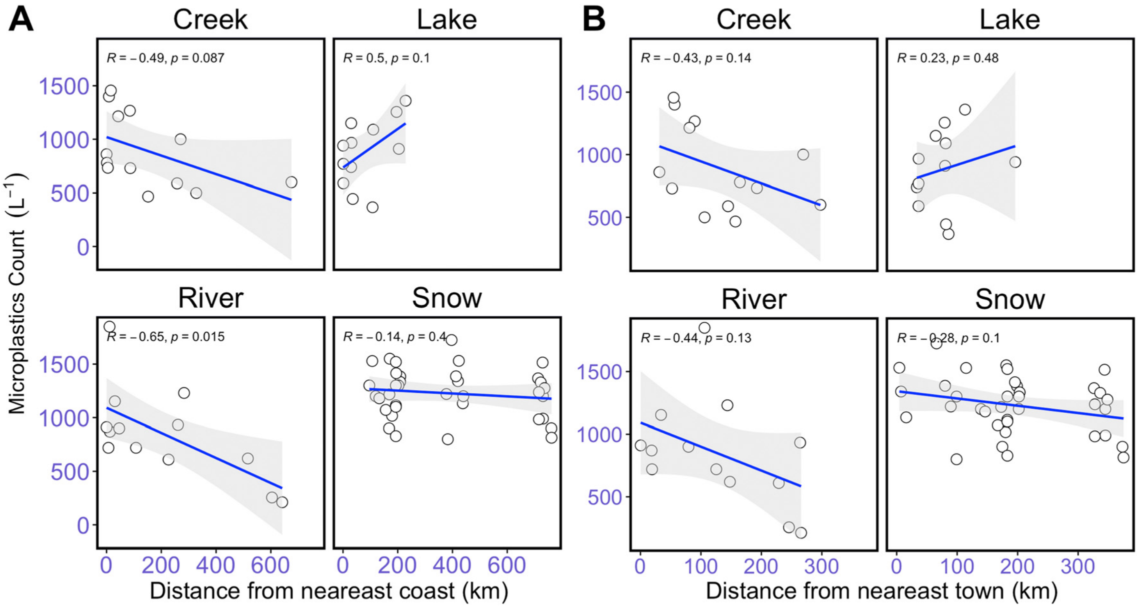

Fig. 6 Correlations of MP counts in snow, river, creek, and lake samples with respect to distance from nearest coast (A) and nearest town (B).

the correlations are not statistically significant. Also, as discussed above, overall MP counts do not have clear correlations with distance from nearest towns or coasts (Fig. S5†).

Alaska's environment is generally pristine, characterized by low population density and minimal visible signs of urban waste disposal or littering, distinguishing it from more densely populated regions. The surface waters studied here remain largely unaffected by wastewater effluent from urban areas. Despite fishing being at the core of subsistence living as well as a key water recreational activity, filament MPs were not dominant in our samples, challenging the notion that fishing significantly contributes to MP pollution in Alaskan waters. Notably, improper landfill management practices are a significant concern in Alaska, particularly in rural communities. However, as our sampling did not include these areas, the direct impact of rural landfills on Alaskan waters remains unassessed. The highest MP counts were observed in snow samples from remote locations in Far North Alaska, suggesting MPs being sourced from precipitation, atmospheric deposition, or atmospheric transmission from nearby urban areas and coasts. This potentially threatens rural communities relying on snowmelt or surface water as drinking water sources.

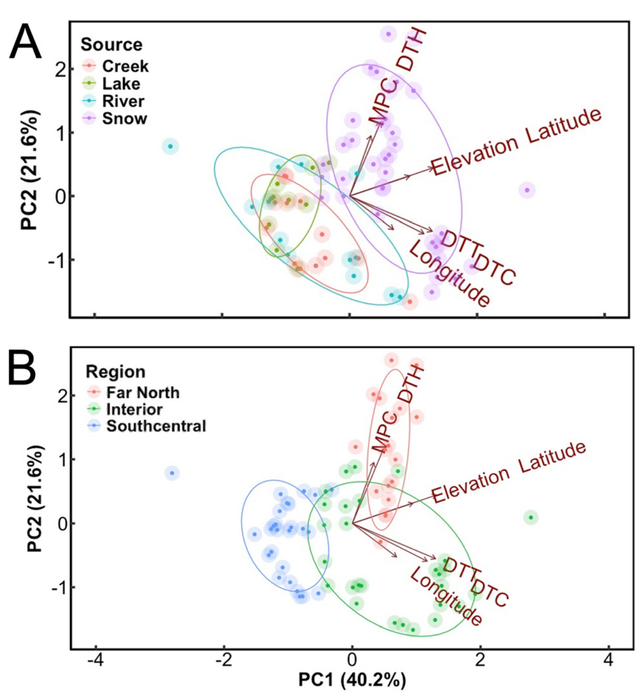

Fig. 7 Principal component analyses of MP counts (MPC), distance to highway (DTH), longitude, distance to coast (DTC), and distance to town (DTT), grouped by sources (A) and regions (B).

Conflicts of interest

There are no conflicts to declare.

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