

From mesenteric lymph nodes to the rest of the body: Microplastic translocation and accumulation in subsistence harvested eastern Chukchi Sea beluga whales

Noelle A Picard

napicard@alaska.edu

University of Alaska Fairbanks College of Fisheries and Ocean Sciences, Department of Marine Biology, Fairbanks, Alaska 99775, United States

John J. Citta

North Slope Borough Department of Wildlife Management, Utqiagvik, Alaska 99723, United States

Katrin Iken

University of Alaska Fairbanks College of Fisheries and Ocean Sciences, Department of Marine Biology, Fairbanks, Alaska 99775, United States

Raphaela Stimmelmayer

North Slope Borough Department of Wildlife Management, Utqiagvik, Alaska 99723, United States

Zachary C. Redman

University of Alaska Anchorage Applied Sciences, Engineering, and Technology Laboratory, ConocoPhillips Integrated Science Building, Anchorage, Alaska 99508, United States

Patrick L. Tomco

University of Alaska Anchorage Applied Sciences, Engineering, and Technology Laboratory, ConocoPhillips Integrated Science Building, Anchorage, Alaska 99508, United States

Brian P. DiMento

University of Alaska Anchorage Applied Sciences, Engineering, and Technology Laboratory, ConocoPhillips Integrated Science Building, Anchorage, Alaska 99508, United States

Lara Horstmann

University of Alaska Fairbanks College of Fisheries and Ocean Sciences, Department of Marine Biology, Fairbanks, Alaska 99775, United States

Research Article

Keywords: beluga whale, subsistence harvest, microplastics, translocation, bioaccumulation, pyrolysis-gas chromatography-mass spectroscopy, Fourier-transform infrared spectroscopy

Posted Date: October 21st, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-11013593/v1>

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Abstract

Beluga whales (*Delphinapterus leucas*) are good sentinels to monitor Arctic ecosystem status due to their longevity, and high trophic, generalist diet. Microplastics (MPs), plastic particles between 1 μm and 5 mm in size, are an emerging contaminant of global concern. Here, we examine MP abundance in eastern Chukchi Sea stock beluga whales that were harvested for subsistence purposes by Alaska Natives. We examined MP concentration in male beluga whale mesenteric lymph nodes (MLN), liver, muscle, kidney, and blubber by extracting MPs via vacuum filtration of digested tissues for isolation and visual inspection of MPs. MP presence was confirmed by mapping molecular composition via Fourier-transform infrared spectroscopy and pyrolysis-gas chromatography-mass spectrometry. MPs were visually detected in all tissues analyzed, with MLNs having the highest and blubber the lowest MP concentrations. MLN had significantly elevated MP concentrations in comparison to muscle, kidney, and blubber; thus, implicating MLNs as a possible site for MP translocation and/or excretion. We showed evidence of MP bioaccumulation in beluga whale muscle, as MP concentrations increase as a function of life stage (based on skin color, $p < 0.05$); however, these trends were not observed for liver, kidney, nor blubber. Bulk stable carbon and nitrogen isotope analysis showed neither trophic position ($\delta^{15}\text{N}$) nor carbon source ($\delta^{13}\text{C}$) were related to MP burden of beluga whales. Overall, a low proportion of isolated MPs yielded positive plastic polymer detections, but polyethylene terephthalate was the most abundant MP polymer identified. These findings further our knowledge of MP accumulation and translocation in the beluga whale, an important Arctic marine mammal.

Highlights

- MPs are most concentrated in mesenteric lymph nodes and least concentrated in blubber.
- There is no significant difference in MP concentrations among liver, muscle, and kidney.
- MPs appear to bioaccumulate in muscle of male beluga whales, based on beluga whale skin color and beluga whale length used as age proxies.
- High MP concentrations in the mesenteric lymph nodes may be associated with feeding events.
- Polyethylene terephthalate, polyethylene, polyamide, and polypropylene were present in beluga whale tissues.

1. Introduction

Beluga whales (*Delphinapterus leucas*) are sentinel species of the Arctic (Choy et al. 2020). Beluga whales are divided into 21 genetically distinct stocks, geographically restricted to the Arctic and sub-Arctic (O’Corry-Crowe et al. 1997; Hauser et al. 2024). Beluga whales are generalist predators with behavioral and dietary adaptability in response to a changing Arctic (Choy et al. 2020). One Alaska beluga stock, the eastern Chukchi Sea (ECS) stock wintering grounds overlap with the sea ice (Citta et al.

2016). They migrate north with annual sea ice recession, making them potential climate change indicators (Hauser et al. 2014). Their restriction to the Arctic also makes beluga whales an important Arctic contaminant indicator species. Beluga whale tissue contaminant concentrations can reveal how the altered landscape may be contributing to changing contaminant burden and, therefore, possible physiological stressors (Loseto et al. 2018).

Beluga whales are often used for contaminant studies, because they are long lived, generalist predators that feed near the top of the food chain (Dehn et al. 2006; Suydam et al. 2009; Quakenbush et al. 2015). In the wild, beluga whales often live 40 + years indicating they are good models to understand bioaccumulation of anthropogenic contamination, because we can monitor contaminant concentration changes over a longer span of time (Suydam et al. 2009; Miller et al. 2020). Their high trophic level combined with substantial diet variation may result in a range in individual diet (e.g., trophic position and carbon source, Dehn et al. 2006; Choy et al. 2020), which can be assessed via bulk stable isotope analysis (Dehn et al. 2006). Coupling individual diet analyses with contaminant analyses therefore allows for the investigation of whether contaminant burden scales with trophic level for biomagnification analysis (Dehn et al. 2006, Quakenbush et al. 2015).

The ECS beluga whale stock, in particular, is an established contaminant model (Loseto et al. 2018). The ECS beluga whales winter near the Bering Strait (Hauser et al. 2014; Citta et al. 2016), at the confluence of the Anadyr and Alaska Coastal Currents (Springer et al. 1996). ECS beluga whales summer along the shelves of the eastern Chukchi and Beaufort seas ranging from Kasegaluk Lagoon to the Mackenzie River Delta (Hauser et al. 2014). The Alaska Coastal Current follows the Chukchi Sea shelf and deposits particles, including microplastic (MP) particles, in sediments, as it meets the Arctic Boundary Current and spreads over the Chukchi Sea (Gong & Pickart 2015). Barrow Canyon, a feeding ground for ECS beluga whales (Hauser et al. 2014), is characterized by upwelling from the influx of warm Atlantic waters, which may increase contaminant suspension in the eastern Chukchi Sea pelagic realm (Li et al. 2022). Due to predation risk, mature and juvenile beluga whales often occupy segregated feeding grounds (Loseto et al. 2006). Juvenile beluga whales feed in shallow, near-shore waters alongside female beluga whales, while adult male beluga whales feed in deep water or near sea ice (Loseto et al. 2006). As a result, juvenile and mature beluga whales can provide valuable insights towards contaminant sources, because of their alternative feeding locations. Differences in food sources can help investigate contaminant variation related to different ecological niches (e.g., benthic invertebrates versus pelagic fishes, Loseto et al. 2006; Quakenbush et al. 2015).

Microplastics (MPs) are emerging contaminants of growing concern in the Arctic (Mu et al. 2019; Zhang et al. 2025). MPs are characterized as plastic particles between 1 µm and 5 mm in diameter or length generally derived from plastics that are manufactured to be this size (e.g., microbeads) or from the breakdown of larger plastics (Thompson et al. 2004). There is a paucity of data on MP distributions, bioaccumulation, and biomagnification in beluga whales and other marine mammals. Moore et al. (2022) described MP abundances in major beluga whale diet components, including Arctic cod (*Boreogadus saida*), Arctic cisco (*Coregonus autumnalis*), fourhorn sculpin (*Myoxocephalus quadricornis*),

and saffron cod (*Eleginus gracilis*, Moore et al. 2022). These authors estimated that beluga whales ingest between 3,811 and 144,996 MPs annually (Moore et al. 2022), showing a wide range of potential MP intake. Therefore, it is important to investigate accumulation properties of MPs to examine the potential for physiological and therefore, ecological consequences.

MPs are stored in Arctic sea ice and are deposited in the water column as the sea ice recedes (Zhang et al. 2025). Annual MP deposition rates from sea ice into the ocean may be exacerbated in the future by increasing annual multi-year ice recession (Kumar et al. 2020). Sea ice extent has been decreasing by approximately 10% per decade over the past 40 years (Kumar et al. 2020). In addition, Arctic air temperatures have increased more rapidly in the past 40 years (+ 3.1 °C) in comparison to the global mean temperature increase (+ 0.8 °C, Kumar et al. 2020). This may place Arctic beluga whale stocks, such as the ECS beluga whale stock, at an elevated risk of MP exposure in their habitat.

MPs in the eastern Chukchi Sea have been identified in the sediment and sea ice in increased concentrations compared to the water column (Mu et al. 2019; Zhang et al. 2025). However, upwelling and current strength into the Chukchi Sea from the North Atlantic and North Pacific oceans, respectively, may increase as the climate warms. Intensified influx of water into the Arctic may increase MP concentrations suspended in the water column (Li et al. 2022; Lakshina & Golubeva 2022). MPs previously identified in the Chukchi Sea and Northern Bering Sea sediment mainly consisted of polyethylene, polyethylene terephthalate, and polypropylene, along with a semi-synthetic non-plastic polymer, rayon (Mu et al. 2019). Most of the MPs identified in the environment are fibers, presumably from textiles (Mu et al. 2019; Dhineka et al. 2024). This is noteworthy, because clothing fibers are often associated with various treatments (e.g., adding polyvinyl chloride to increase durability), which introduce phthalate esters to textile products (Ji et al. 2024). Human, rodent, and *in-vitro* study models have shown that phthalate esters are endocrine disrupting chemicals that may interfere with growth, development, and reproduction in high enough concentrations (Ullah et al. 2023), suggesting potential broader physiological and, thus, ecological implications.

MPs can cross the intestinal barrier into non-digestive tissues, including brain and bones (Lu et al. 2024; Nihart et al. 2025). Although there is still speculation regarding the vector for MP translocation, one hypothesis is that MPs are detected by immune patches in the ileum upon digestion, known as Peyer's patches (Lazaridis et al. 2025). MP detection by the Peyer's patches may elicit an immune response resulting in uptake of MPs across the intestinal barrier via immune macrophages to be distributed throughout the body via the circulatory system (Lazaridis et al. 2025).

In this study, we assessed male subsistence-harvested ECS beluga whale kidney, liver, muscle, and blubber to determine MP distribution and accumulation patterns based on diet indicators (via bulk stable carbon and nitrogen isotopes), age proxies (via total body length and skin color), and tissue. Male beluga whales were the focus of this study, because females may undergo physiological offloading processes, such as gestation and lactation, that could interfere with bioaccumulation analysis (Nash 2018). We address whether MPs, presumably derived from beluga whale prey, bioaccumulate in the body. Findings

provide information about MP burden in various tissues from presumably healthy, free-ranging beluga whales and discuss potential ecological implications of MPs in the Arctic marine food web.

2. Methods

2.1 Sample Collection

Subsistence hunters from Point Lay, Alaska granted researchers affiliated with the North Slope Borough Department of Wildlife Management (NSB-DWM) permission to sample beluga whale tissues from their annual harvest. The beluga whale harvest takes place in June during the annual eastern Chukchi Sea (ECS) beluga whale migration to their summer feeding grounds in the eastern Chukchi Sea (Hauser et al. 2014). Sampling subsistence harvested whales provides the unique opportunity to conduct research on presumably healthy, free-ranging ECS beluga whales. The NSB-DWM has also maintained beluga whale tissue archives from Pt. Lay, Alaska subsistence harvests (1998–2024) stored at -20 °C. Between 5 and 20 g of gray and white gray (juvenile and early adult stage, respectively) and adult (all white) male beluga whale liver, muscle, kidney, and blubber were subsampled and analyzed for each individual in this study for bioaccumulation analysis and correlations of MP burden and trophic level (Online Resource 1, Suydam et al. 2009). The exact weight (grams wet weight) was recorded for each tissue analyzed to determine tissue MP concentration (MP count / total weight). Beluga whale age was approximated by body length (cm) measured in a straight line from the rostrum to fluke notch (Suydam et al. 2009), as dentin tooth layer data were not available for this study. There is some variation in individual beluga whale growth rates resulting in overlap of beluga whale lengths representing life stage (adult versus juvenile, Suydam et al. 2009). Therefore, we used beluga whale skin coloration as a secondary indicator to confirm age proxies based on life stage.

Several mesenteric lymph nodes (MLNs, n = 6) from subsistence harvested beluga whales from Point Lay, Point Hope, and Utqiagvik, Alaska (1997–1999) were also available for analysis. Of the six MLNs assessed, one was from a juvenile female, one from a juvenile male, and four from adult males. Because MLNs were harvested from male and female beluga whales from various stocks, these data were not included in bioaccumulation, biomagnification, nor MP characteristics (color and type) analyses. Four out of the six beluga whales with MLN samples had stomach content data available. Three beluga whales had empty stomachs, and one beluga whale had prey items in her stomach at the time of harvest, suggesting a recent feeding event. MLNs were selected assuming that most MPs enter the body via prey ingestion prior to translocation to other tissues

2.2 Microplastic Extraction

2.2.1 Tissue Digestion and Density Separation

Tissues were digested in clean glass jars to separate the MPs via vacuum filtration as described by Blade & Horstmann (2026). Briefly, tissues were dissolved in 20% potassium hydroxide at a 3:1 ratio (potassium hydroxide volume:tissue weight) and incubated on a rocking platform (low speed) for 24–48

h at 55 °C until the tissue was fully liquified. The resulting digested tissue was then vacuum filtered through a 0.7 µm porosity Whatman glass fiber disc (GF/F) to isolate all MPs larger than 0.7 µm. We added 20 mL of filtered ethanol (200 proof) to some digests, when necessary, to facilitate filtration as some tissues (i.e., blubber and liver) were difficult to filter due to high fat content.

In all tissues, excluding the blubber, a density separation step was conducted to enhance MP identification and characterization by removing the thick, dark residue left behind after vacuum filtering highly perfused digested tissues with dark coloration. The light coloration of blubber made this step unnecessary. The density separation was used as described by Blade & Horstmann (2026). Briefly, the original tissue filter from the previous vacuum filtration step was submerged in 15 mL of a sodium iodide solution (density: 1.7 g/mL) in a 40 mL glass conical tube to separate the MP from the residue via floatation through a series of sonication (5 min), light agitation on an incubated rocker (55 °C for 5 min), and centrifugation (500 x g for 2 min). Centrifugation separates any sediment suspended in the solution from the MPs, because this centrifugal force is sufficient to concentrate sediments to the bottom of the tube, while MPs remain suspended in the solution. The supernatant solution containing MPs was transferred to a clean 0.7 µm porosity Whatman glass fiber filter via vacuum filtration.

2.2.2 Quality Control

The ubiquitous nature of MPs makes contamination avoidance and quality control measures critical. We followed protocols described previously by Blade & Horstmann (2026). Nitrile gloves and a cotton lab coat were worn at all times to ensure standardization of potential contaminant sources. Ultrapure water and all chemical solutions were filtered with a 25–50 µm porosity fritted glass filter disc (Thomas Scientific) prior to use in MP extraction. We decreased the chance of external MP contamination by rinsing all glassware with this filtered water and trimming away the exterior layer of all tissues that could possibly have been contaminated by handling and storage. All tissues were sub-sampled on cleaned stainless-steel surfaces. An atmospheric deposition blank (0.7 µm porosity Whatman glass fiber filters wrapped in clean aluminum foil) was placed in the work area and opened to the surroundings each time a sample was exposed to the atmosphere to estimate airborne contamination for each individual sample, as MP atmospheric concentrations may frequently fluctuate. Atmospheric deposition blank filters were inspected at the end in tandem with the sample, and MP counts on air blanks were then subtracted from the corresponding categories for MP color and type analysis, as well as the final sample count totals. Most of the contamination sources were from the density separation (see section 2.2.1). Therefore, we used method blanks, separate from the atmospheric deposition blanks, to estimate the number of MPs that may be attributed to contamination. We processed triplicate blanks (0.7 µm Whatman glass fiber filters) via density dependent separation in tandem with the samples. The sodium iodide from the method blanks was then filtered onto a new 0.7 µm porosity Whatman glass fiber filter, and MP were counted. The mean method blank MP count was then subtracted from all tissues that underwent the density dependent separation (all MLN, liver, muscle, and kidney). We confirmed that there was no MP contamination derived from digesting the tissues in potassium hydroxide.

2.5 Fourier-Transform Infrared Spectrometry

We used the Nicolet 6700 Reflective μ -Fourier-transform infrared spectrometer (Thermo Scientific) at the University of Alaska Fairbanks Advanced Instruments Laboratory. Reflectance μ -Fourier-transform infrared (FTIR) spectroscopy was carried out as described by Blade & Horstmann (2026). FTIR spectroscopy analysis was conducted in muscle, because muscle had consistently detectable MP particles across individuals. In addition, the low fat content of muscle samples reduced interference from lipid residues on the MP surfaces. Due to similar hydrocarbon structures, lipids commonly produce false detections for polyethylene (Sandt et al. 2021). We analyzed 35 MP fibers at random from 16 randomly chosen beluga whale muscle samples and attempted to analyze four MPs from three blubber samples. Blubber samples were chosen based on a visual inspection of which filters had the lowest fat residue; despite this, lipid contamination in blubber samples complicated analysis and resulted in false identifications, such as soy flour, and precluded further analysis.

Individual MPs were placed onto a sodium chloride salt disc under a dissecting microscope using fine steel forceps for FTIR spectroscopy analysis. This process leads to a bias towards larger MPs that can be manipulated with forceps. For the FTIR spectroscopy analysis, we used an aperture of 50 μ m x 50 μ m and a spectral resolution of 1/4 cm with 270 scans. We selected relatively residue-free sections of the presumed MP surface whenever possible to minimize disruptions to the spectra, and the plastic particles occupied no more than approximately 1/3 of the aperture window to reduce absorbance peak dispersion from excessive reflectance signal. The *OpenSpecy* reference library (Cowger et al. 2025) was used to compare our absorbance peaks to over 40,000 previously mapped spectra. We uploaded our spectra to the ShinyApp (Cowger et al. 2025) to identify potential matches from the derivative library. We show all matches above 50% but only included MPs with a match value above 70% in subsequent analyses to decrease potential error from false identifications and remain consistent with previous publications (Rathore et al. 2023). To ensure the match results were not attributed to background noise, we only analyzed spectra with a signal to noise (S/N) ratio greater than 10 (Cowger et al. 2021). The *OpenSpecy* package (Cowger et al. 2025) was created under R package version 1.5.3 (<https://CRAN.R-project.org/package=OpenSpecy>).

2.6 Pyrolysis-Gas Chromatography-Mass Spectrometry

Pyrolysis-gas chromatography-mass spectrometry (py-GC/MS) was used for molecular mapping and detection of 12 common plastic polymers located in the *F – SearchMP2.1database* (Frontier Laboratories) in the MPs isolated from beluga whale tissues (Online resource 2). Py-GC/MS methods were carried out as described by Santos et al. (2023). MP polymers were identified using a multishot pyrolyzer (Py/EGA3030D, Frontier Laboratories), an autoshot sampler (AS1020E, Frontier Laboratories), and a 6890N gas chromatograph with a 5973 mass selective detector (Agilent Technologies). First, volatile matrix was thermally desorbed from the samples from 100–300 °C (30 °C/min ramp), followed by a hold at 300 °C for three min, to reduce interference during pyrolysis. Suspected particles were pyrolyzed at 600 °C for 0.2 min and the polymer pyrolysis products were separated using an Ultra Alloy UA+ -5 capillary column and a helium carrier gas flow of 1.37 mL/min. The GC inlet temperature was 300

°C and a 1:16 split ratio was used. The gas chromatograph oven temperature remained at 40 °C for two min before ramping at 20 °C/min to 320 °C at 16 min.

We used fine steel forceps to transfer all MPs that were large enough to be manipulated from each sample filter to the stainless steel 5x4 mm EcoCup (Frontier Laboratories) under a dissecting microscope with a deionizer set up at the station. As described above, the MP selection is inherently biased to particles that are large enough to be handled with forceps. Transferring MPs to the tin capsule rather than pyrolyzing the entire filter was necessary to minimize interruption from background signal and to concentrate MPs into one tin to get a sufficient MP mass. Py-GC/MS was conducted on MP isolates of MLN, liver, muscle, kidney, and blubber samples. We added 4 mg of calcium carbonate (Frontier Laboratories) to the pyrolysis cup to act as a diluent and catalyst for pyrolysis. A small amount of quartz wool (Frontier Laboratories) was placed on top of the MP and calcium carbonate mixture to keep the solid samples within each cup. MP calibration standards were analyzed to confirm detection of known MP polymers (Online resource 2). We included an instrument blank consisting of calcium carbonate and quartz wool after every 10 samples. MPs from method blanks and atmospheric deposition blanks were analyzed to assess laboratory contamination. In addition, we processed in-house standard of high-density polyethylene that had been photochemically weathered (Suntest XLS+, Atlas Materials LLC, 250 W/m², 300–800 nm, 15°C, 7 d) in filtered seawater to assess whether photo-oxidation and environmental weathering alter the accuracy of identification. However, it is important to note that the results from the weathered high-density polyethylene may not apply to other MP types.

Polymer detection rates were likely low due to miniscule particle masses, so we combined samples of the same tissue type to increase the particle mass and therefore the potential for polymer detections. The MP calibration standards (Frontier Laboratories) diluted with the 4 mg calcium carbonate inert diluent were used to confirm the effectiveness of these methods and to set minimum detection limits (Online resource 2). All standards provided positive matches (above 90% match value); thus demonstrating that polymers could be qualitatively identified for the purpose of this study. Polymers were identified through the 'Microplastics Analysis using Micro-Furnace Pyrolyzer and F-Search MPs 2.1 Software' (Frontier Laboratories) based on their respective retention time and mass to charge (m/z) ratio. We used *F – SearchMPs2.1software* (Frontier Laboratories) to match polymer spectra in the MP library to the unknown sample spectra and their match value (% correlation). As described for FTIR, we recorded all matches above 50% correlation but only matches above 70% were included in subsequent analyses.

2.7 Stable Isotope Analysis

Bulk stable nitrogen ($\delta^{15}\text{N}$) and carbon isotope ($\delta^{13}\text{C}$) values were measured in beluga whale muscle to assess trophic position and carbon source, respectively, as described by Dehn et al. (2006). Muscle was used, because the turnover rate is estimated to integrate diet over the order of months (Clark et al. 2019). Briefly, the tissues were freeze dried and finely pulverized with mortar and pestle, followed by lipid extraction from a portion of each sample using chloroform/methanol (2:1 by volume) for the stable

carbon isotope analysis. $\delta^{15}\text{N}$ values are affected by lipid extraction; therefore, the non-lipid extracted sample was analyzed for $\delta^{15}\text{N}$ (Horstmann-Dehn et al. 2012). We weighed 0.3–0.7 mg of each sample into a tin capsule. Peptone was used as an internal standard (SD ($\delta^{13}\text{C}$): 0.06 based on five peptone standards; SD ($\delta^{15}\text{N}$): 0.1 based on four peptone standards). Continuous flow mass spectrometry was used for bulk elemental analysis. Samples were flash combusted at 1020 °C and carried through an oxidation column via helium gas. A reduction column was used to finalize the separation of carbon and nitrogen into carbon dioxide and nitrogen gas and was carried into ConFlo III via helium gas to be separated based on isotopic weight and analyzed by an isotope-ratio mass spectrometer (Thermo Delta V+ elemental analyzer). Stable nitrogen and carbon isotopes in samples were standardized to air and Bee-Dee Belemnite, respectively. Lipid-extracted muscle $\delta^{13}\text{C}$ values were corrected for the Suess effect using the R package *SuessR* (Clark et al. 2025). The *SuessR* package (Clark et al. 2025) was created under R package version 0.1.6 (<https://CRAN.R-project.org/package=SuessR>). Suess correction is necessary when analyzing tissues over a longer time period due to increased carbon dioxide fossil fuel emissions since the industrial revolution that are depleted in ^{13}C , as these emissions may offset stable carbon isotope values by > 0.2‰ (exceeding instrument error) over the span of just eight years (Clark et al. 2021). We chose the Bering Sea as the local food web, because ECS beluga whales winter near the Bering Sea until May (Hauser et al. 2014). Although the turnover rate is not known for beluga whale muscle, the turnover rate for large mammals is ~ 134–157 days (Clark et al. 2019). The corrected and lipid-extracted $\delta^{13}\text{C}$ values were used for all subsequent analyses.

2.8 Statistical Analysis

MPs were identified and counted on the glass fiber filters via a Linitron 2850 Series stereomicroscope. MP counts were totaled, then corresponding atmospheric deposition blank and mean method blank counts subtracted. The resulting number was divided by the total digested tissue mass (grams wet weight) to calculate the concentration of MP count per gram of tissue (MP/g). MP color and type (i.e., fiber, fragment, film, bead) were recorded for each particle, as described by Blade & Horstmann (2026). For each tissue analyzed, we grouped MPs based on particle type. MP types included fibers, fragments, and other; the *other* category consisted of microbeads, film, and irregular shaped plastics that did not fit any other category. Fibers were the most common MP types identified; therefore, fibers were then grouped by color from the pooled tissue fibers. *CaptaVision + software* was used to measure MP fiber lengths, fragment length and width, and bead diameters at 40X magnification, unless otherwise noted.

All statistical analyses were performed in R (version 2025.09.0 + 387 R Core Development Team 2023) with a significance level of $\alpha = 0.05$. Due to wide distributions in MP concentrations (Online Resource 3) and sizes (Online Resource 4), we used non-parametric analyses, and we report all data as median +/- one standard deviation (SD), unless otherwise noted. We used a ranked non-parametric pairwise Kruskal-Wallis test to examine differences in concentration of MP types for each tissue and MP colors within our sample pool. A Dunn ranked sum test with a *Holm* p-value correction was performed to determine differences among MP types as well as concentrations of different MP fiber colors among tissues.

In this study, we also analyzed MP concentrations as a function of approximated beluga whale age (using body length and skin color), as well as bulk stable carbon and nitrogen isotope values as a proxy of carbon source and trophic level, respectively. We conducted linear regression on MP concentrations as a function of collection year (1998–2024) in muscle due to more robust sample size, and we found no significant correlation ($R^2 = -0.01$, $p = 0.5$, Online Resource 5). These findings confirm that corrections to MP concentrations based on year of collection prior to bioaccumulation and biomagnification analysis is not warranted, as muscle MP concentrations have remained relatively constant over the collection period. We conducted linear regression on MP concentrations as a function of length and colors as a multiple linear regression analysis, as well as MP concentrations as a function of $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values. Linear model residuals of MP concentrations as a function of length, as well as $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values were not normally distributed and right-skewed. We therefore applied a log transformation to the MP concentrations to regress against beluga whale length (cm) and $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values (‰). We used a Kruskal-Wallis test to assess MP concentration differences between juvenile (gray), early adult (white gray), and adult (white) beluga whale muscle tissues.

3. Results

3.1 Microplastic Tissue Concentrations

Mesenteric lymph nodes (MLNs) had significantly higher MP concentrations (MP/g) compared to muscle, kidney, and blubber ($p < 0.001$, Fig. 1). MLN had higher median concentrations than liver, although this difference was not significant ($p = 0.08$). Liver, muscle, and kidney tissue MP concentrations were not significantly different ($p > 0.05$, Fig. 1). Median MP concentrations were 2.6 ± 6.5 MP/g for MLN, 1.3 ± 1.3 MP/g for liver, 1.0 ± 1.3 MP/g for muscle, 0.9 ± 0.4 MP/g for kidney, and 0.4 ± 0.3 MP/g for blubber (Fig. 1). Isolated and visually identified MPs included fibers and fragments, along with microbeads, film, and fiber bundles categorized as *other* for analysis purposes (Fig. 2). The general proportions of each MP type were approximately the same across all tissues, with fibers being significantly more abundant than other MP types in all tissues ($p < 0.001$, fibers were 98.4% of total MP count in liver, 91.6% in muscle, 92.3% in kidney, 100% in blubber, Fig. 3).

We pooled all fibers across all tissues for a description of particle color. Clear (0.3 ± 0.7 clear fibers/g), black (0.3 ± 0.5 black fibers/g), and blue (0.2 ± 0.5 blue fibers/g) were the most prominent colors across all tissues (Fig. 3). Other colors, such as brown, red, and green fibers were present in lower numbers.

As mentioned, fibers were by far the most abundant MP types, so we measured fiber lengths to compare MP sizes in beluga whale tissues. There was no difference in MP fiber lengths among tissue types (Online resource 4). Of the MPs measured in each tissue, the widest MPs were all fragments, and were as follows: 39 μm in muscle, 35 μm in liver, 30 μm in kidney, and 53 μm in MLN. All MPs identified in blubber were too narrow to measure their width. The largest MPs (both by length and width) were observed in the MLN (4.5 mm (fiber) and 53 μm (fragment), respectively).

We correlated muscle MP concentrations to beluga whale length (as a proxy for age, Suydam et al. 2009) to assess potential MP bioaccumulation. We ran a multiple linear regression of MP concentrations as a function of length and color, and found that the results were significant for beluga skin color ($R^2 = 0.2$, $p = 0.04$, Fig. 4). All regression parameters are included in Fig. 4. We also used a non-parametric pairwise Kruskal-Wallis test to compare MP concentrations amongst life stages (juvenile, juvenile/early adult, and adult) due to the wide range in MP concentrations, and found a significant difference between the juvenile (gray) and adult (white) life stages (Fig. 4, $p = 0.02$).

Stable carbon and nitrogen isotope ratios in male subsistence harvested beluga whales showed a narrow range ($\delta^{15}\text{N}$: 15.5 to 17.2‰; $\delta^{13}\text{C}$: -18.6 to -17.2‰). The mean $\delta^{15}\text{N}$ value was 16.4 ± 0.4 ‰ and the mean $\delta^{13}\text{C}$ value was -17.7 ± 0.4 ‰. To address potential biomagnification of MPs, we regressed muscle MP concentrations on $\delta^{15}\text{N}$ values; the relationship was not significant ($R^2 = 0.06$, $p = 0.08$, Online Resource 6). Regression of muscle MP concentration on lipid-extracted and Suess-corrected $\delta^{13}\text{C}$ values was also not significant ($R^2 = 0.02$, $p = 0.2$, Online Resource 6).

3.2 Microplastic Polymers

Of 35 MPs isolated from beluga whale muscle and four MPs isolated from beluga whale blubber that were analyzed using FTIR, 13 spectra yielded match values of above 50% with S/N above 10. Of the analyzed spectra, one had a match value above 90%, five had a match value 80–90%, and six had a match value 70–80%. Among the absorbance peaks with a match value above 70%, only three were plastic polymers, consisting of two nylon-6,6 matches and 1 polypropylene match (Table 1). Of the spectra with a match value 50–70%, possible polymer matches included viscose (semi-synthetic polymer), silicone rubber, poly(acrylimide/amid) rubber, polystyrene, ethylene-acrylate-monomer, polyethylene rubber, polyethylene (low density), and acrylonitrile butadiene styrene (Table 1).

We used py-GC/MS to analyze all isolated MPs that had not been analyzed by FTIR and were large enough to manipulate with fine forceps, as MP particles that underwent FTIR spectroscopy analysis were not returned to the glass fiber filter to prevent double sampling. Of the blanks analyzed, one had a polyurethane detection with a match value of 88%; therefore, three polyurethane matches on kidney MPs are not reported assuming likely airborne contamination. A method blank yielded a 94% match value for polycarbonate, and therefore, we did not report one polycarbonate match collected from a muscle tissue filter. While analyzing the isolates from tissue samples, we found very few positive plastic polymer detections despite the standards showing a relatively low threshold for detection.

Of 65 beluga whale samples analyzed, 10 had polymer match values above 50%. Of those polymers, two had match values of 70–80%, one had a match value of 80–90%, and five had match values above 90%. Table 2 summarizes plastics identified with a match value above 70%, which included four polyethylene terephthalate matches, two polyethylene matches, and one nylon-6,6 match. Of the one sample with match values 50–70%, the polymer was identified as nylon-6,6. The beluga whale tissues with positive MP detections (match value above 70%) were MLN, muscle, kidney, and blubber. In all cases, the polymer

mass was below the minimum value of the standard masses tested, suggesting all polyethylene terephthalate samples were below 0.28 µg, nylon-6,6 samples were below 0.32 µg, and polyethylene samples were below 2.8 µg.

4. Discussion

MPs are emerging contaminants that have gained a lot of traction in environmental and health studies due to their ability to translocate over the gut barrier and distribute throughout the body (Merrill et al. 2023). MP translocation in the body is hypothesized to potentially be associated with fibrosis, inflammation, and endocrine disruption, suggesting they could have potential ecological consequences (Li et al. 2023; Ullah et al. 2023). MPs have been identified in spotted seal (*Phoca largha*) stomachs from the Bering and Chukchi seas, as well as polar bear (*Ursus maritimus*) feces from the Canadian Arctic (Iyare et al. 2024; Sletten et al. 2025). Furthermore, instances of MP translocation into tissues have been identified in several Arctic marine mammals, including beluga whale blubber and melon (Merrill et al. 2023), as well as Pacific walrus (*Odobenus rosmarus divergens*) blubber and muscle (Blade & Horstmann 2026). We showed that MPs are present to varying degrees in tissues of subsistence harvested male eastern Chukchi Sea (ECS) beluga whales, with evidence of bioaccumulation in the muscle as beluga whales age. The majority of isolated MP particles that we were able to identify were polyethylene terephthalate, polyethylene, polypropylene, and nylon-6,6 fibers.

4.1 Microplastic Distribution and Potential Uptake Mechanisms

Beluga whale mesenteric lymph nodes (MLNs) had the highest MP concentration compared to liver, muscle, kidney, and blubber; although MLN MP concentrations were not significantly higher than liver MP concentrations. If the main route of MP entry into the body is ingestion, immune cells in the ileum, Peyer's patches, may play a role in MP uptake, translocation, and/or excretion (Banerjee & Shelver 2021). Macrophages in Peyer's patches are responsible for pathogen identification and removal and may alert immune cells to also phagocytize MPs (Lazaridis et al. 2025). Rodent studies have found labeled polystyrene (PS) particles as large as 1 µm in the MLNs following ingestion, and these particles were cleared within 36 hours of translocation (Banerjee & Shelver 2021). Our study found larger MPs (up to 53 µm wide and up to 4.5 mm long) in the MLNs suggesting that larger MPs than previously observed in rodents can be taken up by beluga whale MLNs. Clearance time of MPs from the kidney, spleen, and liver is size dependent with larger MPs taking longer to be excreted from the body (Banerjee & Shelver 2021). If this is consistent for MPs in the MLNs as well, larger MPs may have longer residence times in the MLNs. We also identified larger MPs up to about 4 mm in length in the liver, muscle, kidney, and blubber, indicating they may be associated with longer clearance times. Long-term presence of MPs in the body may lead to increased buildup of reactive oxygen species, decreased immune function, and chronic endocrine disruption (Li et al. 2023; Ullah et al. 2023).

Further evidence of the potential MLN role in MP uptake following ingestion is that the MP concentration distribution for the MLN in this study was bimodal. While sample sizes were small, of the six beluga whales with MLN samples, four had records of presence or absence of stomach contents. Of the three beluga whales with empty stomachs at the time of harvest, the MLN concentrations were relatively uniform (2.8 ± 0.2 MP/g). Conversely, the MLN of one beluga whale with stomach contents upon collection had a high MP concentration (16.3 MP/g). MPs may therefore be taken up by the MLNs following feeding events and translocated into the body.

Based on human studies, it is likely that the circulatory system is responsible for MP distribution to body tissues (Leonard et al. 2024). This would explain the higher MP concentrations in highly vascularized tissues, such as liver, muscle, and kidney compared to blubber. Blubber has low perfusion and relatively high turnover rates (Ball et al. 2017), which may be the reason for lower observed MP concentrations. Our MP findings for beluga whale blubber are comparable to those previously determined by Merrill et al. (2023) in beluga whale blubber and acoustic fat pads. In addition, our blubber MP concentrations are comparable to those of Pacific walruses from the eastern Chukchi Sea implying that MPs are consistently low in low perfused tissues in comparison to tissues with higher vascularization (Blade & Horstmann 2026). In this study, liver had higher MP concentrations than other tissues without evidence of bioaccumulation. The high MP concentrations in liver may be a result of the detoxification processes in this organ that include clearing MPs from the body (Banerjee & Shelper 2021). Kupffer cells, stationary macrophages in the liver, may remove MPs from the liver for excretion (Willekens et al. 2004). However, MPs likely build up in the liver prior to excretion due to MP presence in the blood (Leonard et al. 2024), explaining the observed high concentrations. One potential route of MP excretion is uptake and transport with old or damaged red blood cells via Kupffer cells, because MPs are present in the blood stream (Willekens et al. 2004; Leonard et al. 2024). The kidneys may also play a role in MP filtration of smaller MPs and nanoplastics, as MPs have been detected in human urine (Pironti et al. 2022). However, there has been no evidence of MPs larger than 15 μm being filtered through the human kidneys (Pironti et al. 2022). Many MPs that we visually identified in beluga whale kidneys were too large to be ultrafiltered in the kidney (Adhipandito et al. 2021), indicating that they may be associated with blood circulation through the kidney rather than the organ itself. This is supported by the relatively uniform MP concentrations in beluga whale muscle, liver, and kidney; all are highly perfused.

Skeletal muscle is highly vascularized; therefore, it is likely that muscle is a location with chronic exposure to MPs (Lu et al. 2024; Blade & Horstmann 2026). For example, preliminary bowhead whale (*Balaena mysticetus*) studies have shown that MP concentrations in blood are comparable to muscle suggesting that a majority of MPs identified in muscle may not have translocated from the blood into the tissue (Horstmann, in prep). *In-vivo* rodent studies used histopathology to show that, despite their ability to enter the blood stream, MPs greater than 100 nm are not readily translocated into tissues following acute MP exposure (Hong et al. 2025), further supporting that MP concentrations are attributed to tissue perfusion rather than MP accumulation potential. However, the accumulation properties of MPs are still largely unknown. Despite previous studies suggesting MPs above 100 nm are not readily accumulating into tissues, our study found evidence of bioaccumulation of MPs in beluga whale muscle. The MP

differences based on life stage were not attributed to differences in diet, as shown by the narrow range in stable nitrogen isotope values across our samples, further supporting evidence of bioaccumulation of MPs in the body. This suggests that while the bulk of MPs are likely in blood, chronic exposure of MPs may eventually lead to bioaccumulation in muscle fibers.

There was no evidence of bioaccumulation in any of the other tissues (i.e., liver, kidney, blubber). There was a wide spread in muscle MP concentrations for larger beluga whales resulting in a poor regression fit. Even though tooth age estimates for our belugas were not available, body length is a good substitute for age, because in general, larger beluga whales are older than smaller beluga whales (Suydam et al. 2009). Yet, age estimates from growth layer groups could provide a better resolution for the larger male whales due to length reaching an asymptote in males that are approximately 25–30 years of age (Suydam et al. 2009). Bioaccumulation of MPs could have health implications for belugas, as rodent studies showed that long-term MP exposure may lead to disruptions of lipid metabolism and homeostasis, which are important mechanisms for marine mammal physiology (Ball et al. 2017; Li et al. 2022). In addition, polystyrene beads orally administered to rodents in *in-vivo* studies interfere with metabolism, muscle fiber morphology, and muscle regeneration following injury after just one month of exposure (Hong et al. 2025). MP bioaccumulation in muscle may, therefore, have ecological consequences, as it may impact locomotion in migratory marine mammals (Lu et al. 2024; Chakraborty & Pal 2025).

We estimated individual beluga diet via bulk stable carbon (indicative of sea ice or benthic association) and nitrogen (related to trophic level) isotope analysis in muscle to investigate MP food web associations. Despite the reported range in beluga diet items (Quakenbush et al. 2015), we did not observe a large spread in muscle bulk stable carbon nor nitrogen isotope values. There was no correlation between beluga stable carbon and nitrogen isotope values and muscle MP concentrations. Although diet certainly impacts MP ingestion, it is likely that other factors contribute to accumulation or elimination of MPs in tissues. For instance, a meta-data analysis showed that MP burden is dependent on feeding mode and location, with pelagic fishes having higher MP concentrations than demersal species (Miller et al. 2020). Due to the lack of variation in beluga stable isotope values, we cannot say with certainty whether diet plays a critical role in MP burden of marine mammals. Future studies investigating MP concentrations in beluga tissues from individuals with known variation in feeding locations would provide valuable insights into whether feeding locations may lead to variation in MP exposure (e.g., open ocean beluga populations versus river and estuary users).

4.2 Microplastic Polymer Identification

We had low plastic polymer detection rates from isolated MPs analyzed via pyrolysis-gas chromatography-mass spectroscopy (py-MS/GC) and Fourier-transform infrared (FTIR) spectroscopy. We confirmed the presence of polypropylene, polyethylene terephthalate, and polyethylene; all having above 90% match values with these polymers. Nylon is also likely present in beluga whale tissues (above 80% match value). Polyethylene terephthalate, polyethylene, polyethylene, and nylon fibers are often not inherently fortified with phthalate ester plasticizers; however, textile fibers are often coated with

polymers and chemicals, such as polyvinyl chloride, to improve texture and durability of clothing (Ji et al. 2024). These in turn are tied to phthalate ester plasticizers and therefore lead to a tight affiliation of many textile fibers with phthalate ester contamination (Ullah et al. 2023; Ji et al. 2024). Phthalate esters act as endocrine disruptors in human, rodent, and *in-vitro* studies (Ullah et al. 2023). Routti et al. (2021) showed that one common phthalate ester, di(2ethylhexyl) phthalate, has impacts on the Thyroid Receptor Beta influencing expression of triiodothyronine steroids and, thus, potentially growth and development (Routti et al. 2021). The Thyroid Receptor Beta is highly conserved in beluga whales (Routti et al. 2021), which suggests that these *in-vitro* endocrine disrupting findings may have ecological implications for the beluga whale population.

The plastic polymers we identified are similar to those described by Merrill et al. (2023), who found that polyethylene, polyethylene terephthalate, and polyester were the most common MP polymers in beluga blubber and melon fat (Merrill et al. 2023). Zhang et al. (2025) showed abundant MP polymers present in landfast sea ice from the Chukchi and Beaufort seas consisted of polyethylene terephthalate, polyethylene, and nylon-6,6 (Zhang et al. 2025), which is consistent with MPs we identified in ECS beluga tissues. Polypropylene was the most abundant polymer in Chukchi Sea and Northern Bering Sea sediments followed by polyethylene terephthalate and rayon (Mu et al. 2019). Although we identified polypropylene in one of the isolated MPs, polyethylene terephthalate was more abundant in beluga tissues. This difference may be because polypropylene has higher resilience to environmental degradation (Guan et al. 2023). It is likely that despite the high proportion of polypropylene in the Chukchi Sea and Northern Bering Sea sediments, polypropylene fibers may not be broken down enough to be frequently translocated into tissues compared to polyethylene terephthalate (Guan et al. 2023). D'Angelo et al. (2023) identified polyvinyl chloride as the most prominent polymer in sea ice of the Chukchi and Beaufort seas; however, we did not have any positive identifications of polyvinyl chloride in beluga tissues via FTIR nor py-GC/MS. These differences in findings may be attributed to FTIR detecting the polyvinyl chloride coating on the surface of environmental polyester fibers, whereas that coating may have been worn away as digestion and translocation expedite MP breakdown (Tamargo et al. 2022; Ji et al. 2024). Polyvinyl chloride may be present in beluga tissues in quantities that are too small to be detected, because the polyvinyl chloride detection limit for py-GC/MS was high compared to most other MPs.

The high prevalence of polyvinyl chloride in Arctic sea ice could be significant to the ECS beluga whale population, as polyvinyl chloride leaches phthalate esters (Henkel et al. 2022). Conducting phthalate ester analysis on tissue samples in tandem with MP analyses will provide more insights into the ecological role of MPs. Currently, there is a lot of speculation regarding the ecological consequences tied to MPs in the environment; however, this is dependent on various chemicals fortifying MPs. Phthalate esters are known endocrine disruptors (Ullah et al. 2023). Studies in the North Atlantic and Arctic have shown that phthalate esters are present and highly variable in liver, muscle, and blubber of several marine mammals, including bowhead whales, fin whales (*Balaenoptera physalus*), blue whales (*Balaenoptera musculus*, Routti et al. 2021). Plastic polymers, such as polyvinyl chloride, can leach

phthalate esters from 49 to over 500 years speaking to their longevity in the ecosystem (Henkel et al. 2022), making understanding their presence and role in ecosystems a priority.

4.4 Limitations to Detecting Microplastic Polymers

The limited polymer identification success is likely caused by several molecular modifications to the polymers during their production to fit a variety of purposes, including color (Azari et al. 2024; Ji et al. 2024), which complicates identification of exact MP polymers isolated from tissues. The limitations of MP identification are likely due to the absence of an accessible database that is specialized in plastic materials with polymer modifications and co-polymers. In general, py-GC/MS methods appeared to result in less peak dispersion and background noise compared to FTIR spectroscopy analysis. This indicates py-GC/MS may be a good method for MP polymer identification once a more robust polymer database becomes available. In addition, it is possible that many potential MP matches may be present in quantities below the minimum detection limit and go undetected. Many polymer detection methods that are currently available are geared towards larger environmental plastics rather than MPs that have translocated into tissues.

In most cases, FTIR spectroscopy results did not provide high confidence in polymer matches. We used a signal to noise (S/N) ratio cutoff of 10 for FTIR spectroscopy analysis, because background noise often causes dispersion of wavelength refractions, which may lead to false identifications (Cowger et al. 2021). In the case of FTIR spectroscopy, we received various results that appeared to be false. Of the matches with a S/N above 10, there were four matches with soy flour (82%, 73%, 72%, and 67% match). These false identifications are likely due to breakdown and photo-oxidation of environmental MPs, altering the surface structure (Rostampour et al. 2024; Su et al. 2024). The surface structure alterations may have impacted our MP detections. In addition, adding dyes to plastic polymers during production has been shown to interfere with accurate FTIR detections (Azari et al. 2024). Alternatively, semi-synthetic polymers include cellulose structures (such as rayon) and natural rubbers (such as neoprene), which are often included in textiles (Mu et al. 2019). In this study, FTIR spectroscopy showed that viscose, a semi-synthetic polymer derived from cellulose, was present among non-plastic polymers.

5. Conclusion

The presence of MPs in ECS beluga whale MLN, liver, muscle, kidney, and blubber provides information about MP distribution throughout the body, as well as potential uptake, translocation, and excretion mechanisms. Elevated MP concentrations in MLN in comparison to other tissues suggest that MPs are likely taken up via the lymphatic system and may be excreted after entering circulation, either by the liver or kidneys depending on MP size. Beluga whale muscle shows evidence of MP bioaccumulation, which indicates possible ecological consequences of MPs for migrating marine mammals, such as beluga whales. The increased abundance of polyethylene terephthalate in comparison to other polymers has important physiological implications, as polyethylene terephthalate textile fibers are often associated with phthalate esters (Ji et al. 2024). This study contributes to the growing body of literature showing that MPs are prevalent in Arctic marine mammals (Merrill et al. 2023; Sletten et al. 2025; Blade &

Horstmann 2026). We provide some evidence of MP bioaccumulation in marine mammals due to the robust sample size of non-stranded free ranging beluga whales. Steps should be taken to alleviate the ecological stressors attributed to plastics. For instance, encouraging decreased waste (i.e., buying clothes second hand, using reusable water bottles, and using cloth grocery bags) is important to reduce environmental plastics. MPs are emerging contaminants, and we still do not know the impact they have on wild populations; therefore, it is crucial to be mindful of plastic use and disposal.

Declarations

7.1 Acknowledgements

We thank the beluga hunters of the Native Village of Point Lay for welcoming us into their community and providing samples from subsistence harvested whales. Stable isotope analysis was conducted by T Howe and S Daniels with the Alaska Stable Isotope Facility. Fourier-transform infrared spectroscopy was done under the guidance of J Larsen and the University of Alaska Advanced Instrumentation Laboratory. Pyrolysis-gas chromatography-mass spectroscopy was conducted at the University of Alaska Anchorage Applied Sciences, Engineering, and Technology Laboratory. Beluga whale samples were collected under National Marine Fisheries Service collection permits 792-1399, 782-1694, 814-1899, 17350, 26667, and their amendments, issued to the North Slope Borough Department of Wildlife Management. This project was supported by the Rasmuson Fisheries Research Center Graduate Fellowship, Alaska National Science Foundation Established Program to Stimulate Competitive Research: Fire and Ice travel funding, the Stephen R. Okkonen memorial research award, the Feder and Shaw award, the Byrd award, and University of Alaska Fairbanks Transformative Experience funding.

7.2 Funding

Student stipend and salary were funded by the 2024-2025 and 2025-2026 Rasmuson Fisheries Research Center Graduate Fellowship. Travel for sample collection to Point Lay and Utqiagvik, Alaska was funded by the Alaska National Science Foundation Established Program to Stimulate Competitive Research: Fire and Ice travel funding (#OIA-1757348) and the University of Alaska Fairbanks Transformative Experience funding. Travel to conferences to share data and to the Applied Sciences, Engineering, and Technology Lab at the University of Alaska Anchorage to conduct pyrolysis-gas chromatography-mass spectrometry was funded by the Stephen R Okkonen memorial research award, the Feder and Shaw award, and the Byrd award. The authors declare that no funds, grants, or other support were received during the preparation of this manuscript. All funding listed was awarded to corresponding author N Picard.

7.3 Authors' contributions

All authors contributed to study concept and design. Project design, data collection and analysis, and original manuscript compiling was performed by N Picard. All authors contributed to manuscript edits and additional suggestions. Project supervision and methodology was performed by L Horstmann. Methodology for using pyrolysis-gas chromatography-mass spectroscopy for identifying microplastics

was created by Z Redman, B DiMento, and P Tomco. Samples and sample data (i.e. corresponding color, sex, and length) were provided by J Citta and R Stimmelmayer. All authors read and approved the final manuscript.

7.4 Ethical approval

Beluga whale samples were provided by subsistence hunters under National Marine Fisheries Service collection permits 792-1399, 782-1694, 814-1899, 17350, 26667, and their amendments, issued to the North Slope Borough Department of Wildlife Management. All samples were collected opportunistically under these collection permits. This research is exempt from University of Alaska Fairbanks Institutional Animal Care and Use Committee oversight as samples were collected opportunistically during legally authorized subsistence harvests by Alaska Natives as allowed under the U.S. Marine Mammal Protection Act (Section 101(b)).

7.5 Consent to participate

Point Lay subsistence hunters provided tissues to researchers following the subsistence harvest and approved of their use for microplastic research. No further consent to participate is applicable to this research as no human subjects were involved in the research itself.

7.6 Consent to publish

Consent to publish is not applicable to this research as this manuscript does not contain any human subjects, individual data, nor identifiable details.

7.7 Competing Interests

The authors have no relevant financial nor non-financial interests to disclose.

7.8 Data Availability Statement

These data are all available from the corresponding author, N Picard, upon request. The corresponding author can be contacted via email at napicard@alaska.edu.

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Figures

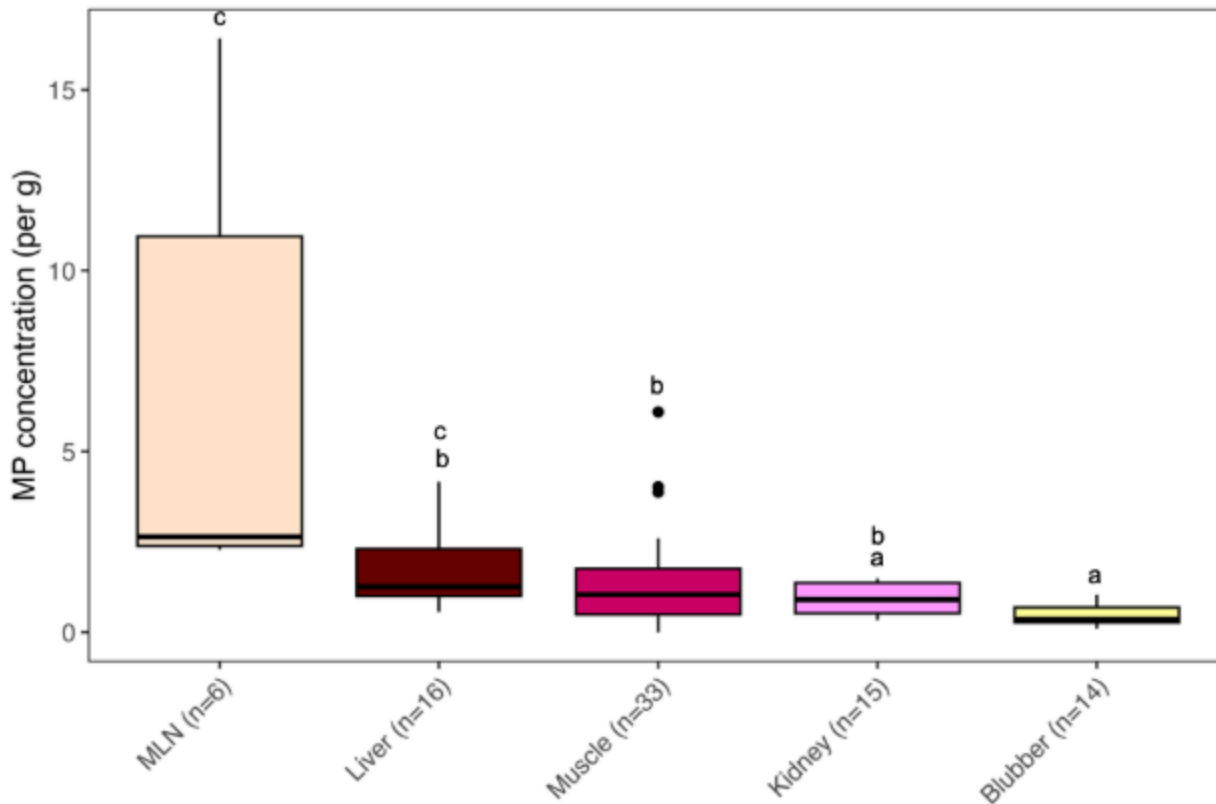


Figure 1

Microplastic (MP) concentration (count per gram tissue) in subsistence harvested Eastern Chukchi Sea male beluga whale tissues. Tissues include mesenteric lymph nodes (MLN), liver, muscle, kidney, and blubber. MLN had higher MP concentrations in comparison to blubber, kidney, and muscle ($p < 0.05$) but were not significantly different from liver ($p > 0.05$). Blubber had lower MP concentrations compared to kidney, muscle, and liver ($p < 0.001$). Whiskers denote one standard deviation above and below the median. Dots represent upper outliers, calculated by $3rd\ quartile + 1.5 * (3rd\ quartile - 1st\ quartile)$. Significance is denoted by differences in letters (e.g., the *b* and *c* above liver insinuates that it is not significantly different from tissues labeled *c* (MLN) nor *b* (muscle and kidney) but is significantly different from tissues labeled with just *a* (blubber), $p < 0.05$). Sample sizes are included with x-axis labels.

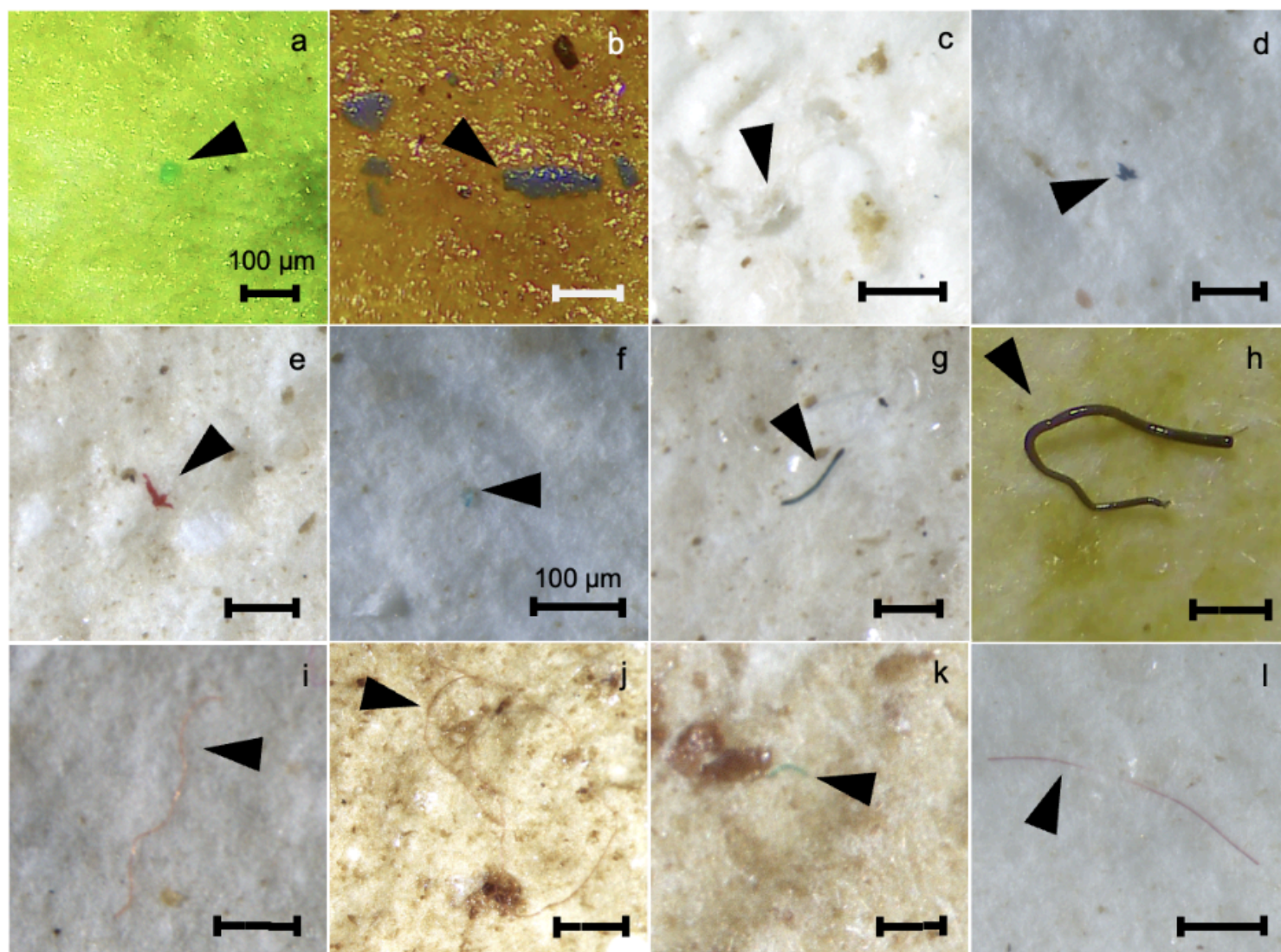


Figure 2

Examples of microplastic (MP) particles isolated from subsistence harvested beluga whale mesenteric lymph nodes, liver, muscle, kidney, and blubber. MP types and colors in this figure include: (a) blue microbead, (b) blue film, (c) clear intertwined fibers, (d) blue fragment, (e) red fragment, (f) blue fragment, (g) blue fiber, (h) black fiber, (i) orange fiber, (j) clear fiber, (k) blue fiber, and (l) red fiber. Black arrowheads assist in pointing out MPs. Scale bars are present in the bottom corner of each MP image and represent 200 μm unless otherwise noted. Each MP was captured at 40X magnification, except the microbead (a) and fiber (f), which were captured at 50X magnification.

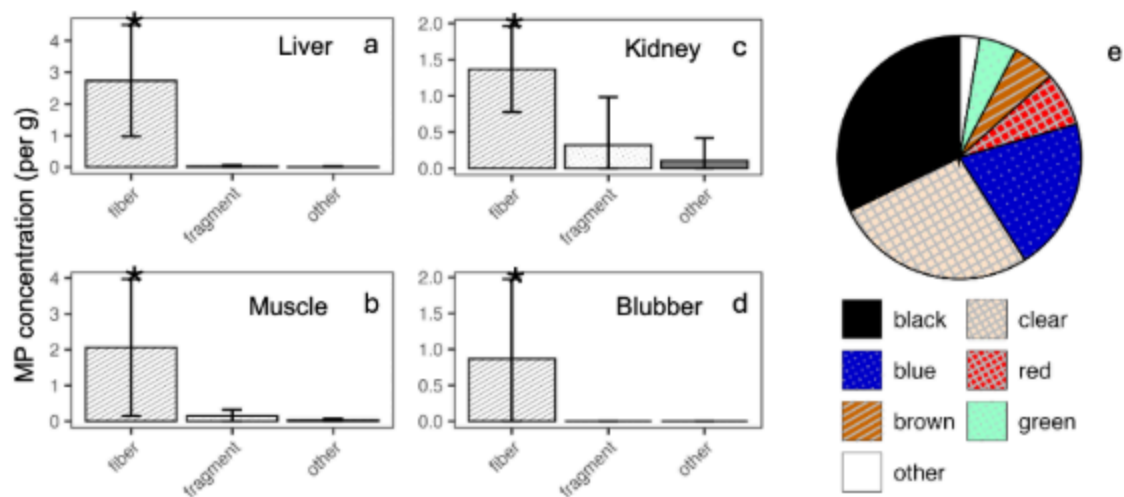


Figure 3

Concentration of microplastic (MP) (count per gram of tissue) of visually identified fibers (blue), fragments (orange), and 'other' (microbeads, film, aggregations; pink) from subsistence harvested Eastern Chukchi Sea male beluga whales (a-d). Whiskers represent 1 standard deviation. There are significantly higher fiber concentrations in comparison to other categories. Statistical significance is denoted by asterisks ($p < 0.05$) is denoted by asterisks. Pie chart (e) highlights the proportion of each color per total fiber counts pooled across all tissues. The legend on the right shows MP fiber color.

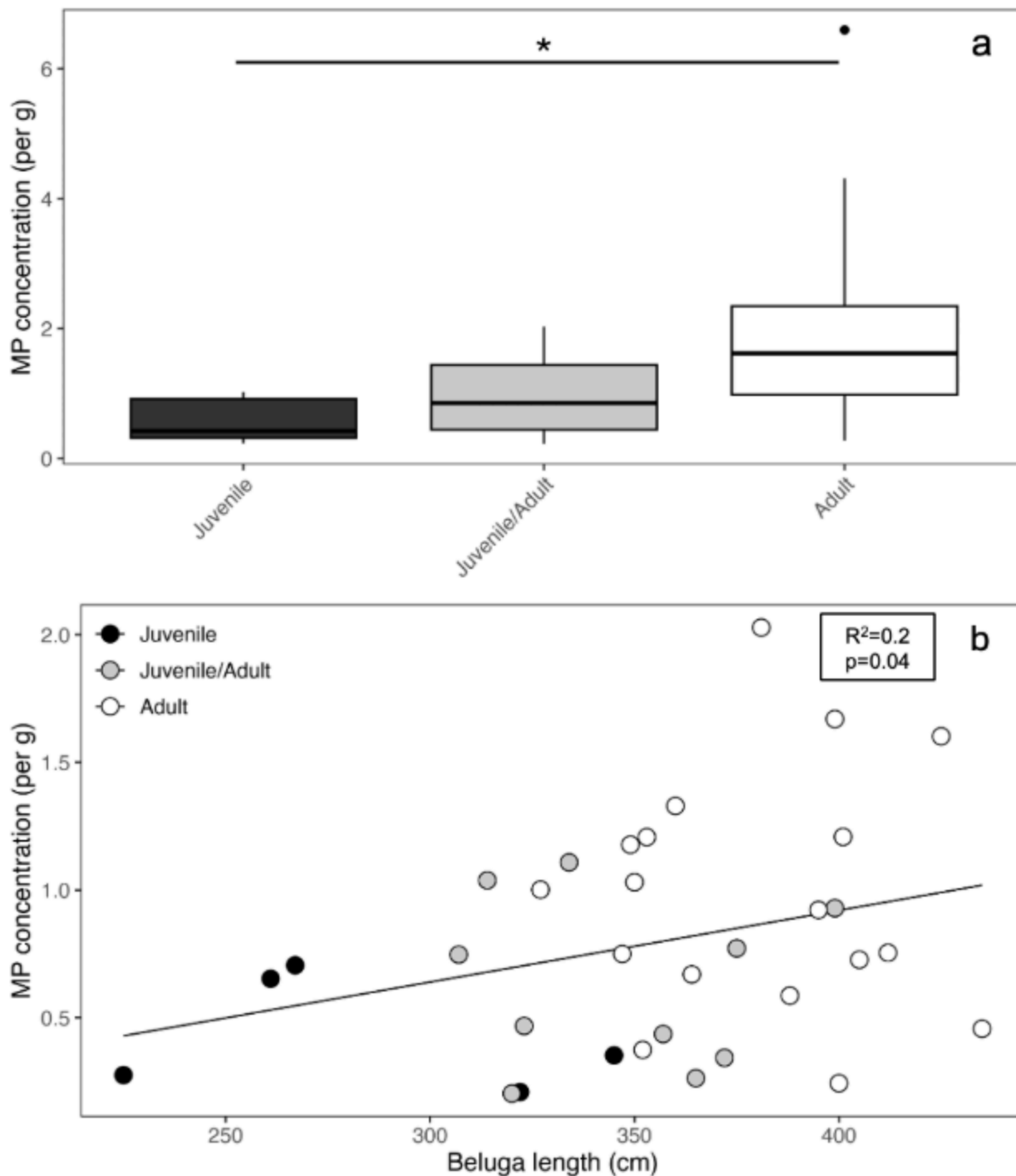


Figure 4

Microplastic (MP) concentrations (count per gram tissue) as a function of beluga whale life stage and total body length (rostrum to fluke notch) as a proxy of age. (a) boxplot of median $\pm$ 1 standard deviation MP concentrations for each life stage, categorized by color. Gray beluga whales are categorized as juveniles (black bar); gray white beluga whales are either juveniles or early adults (gray bar); and white beluga whales are considered adult (white bar). Significance is denoted by the asterisk ($p=0.04$). Outlier is denoted by black point. (b) linear regression of log transformed MP concentration as a function of beluga whale length and life stage (indicated by symbol color). Symbols are representative

of beluga whale life stage based on skin color: juvenile (black), juvenile or early adult (light gray), and adult (white). Regression parameters of MP concentration as a function of life stage (color) are in the top right corner.

Supplementary Files

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