Final Report
Cruise: ED142408-TRYK

Coastal State	Authorization Document Number	National Participant(s)
Norway	24/4590	NA
United Kingdom (Shetland Islands)	47/2024	NA
Denmark (Faroe Islands)	JTHAV File No. 24/21819	NA
Iceland	UTN24030541	NA

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Brief description of scientific objective:

The primary objectives of our research were to:

-Investigate microplastic and anthropogenic microfiber in the air and surface waters throughout our voyage on the *NG Endurance* with Lindblad Expeditions and National Geographic, including the surface waters/air along the expedition cruise track.

-Engage onboard guests and field staff as citizen scientists to complete the sampling, taking action to understand the problems our ocean faces and, in turn, be inspired to be part of the solutions.

-Further refine CSI for the Ocean's methods and equipment. This program was inspired by and uses forensic science methodology to utilize affordable equipment and accessible techniques so people of all ages can engage in meaningful and robust science that provides data that supports solutions to the problem of microplastic and anthropogenic microfiber pollution. Locations where these methods have been tested and deployed to date include the Hudson River in New York State, the Hawaiian Archipelago, Greenland, Arctic Svalbard, fjords of Norway, Falkland Islands, South Georgia and Antarctica. Using the same methods along the expedition route of the *Endurance* (Norway, Shetland Islands, Faroe Islands and Iceland) will provide valuable information for this growing global database.

-Share the data from our sampling openly, making it accessible to community members, fellow scientists, and all stakeholders interested in microplastic and anthropogenic microfiber pollution.

-Use the data from this expedition and beyond to underpin the development and deployment of solutions to microplastic and particularly microfiber pollution. Our global dataset, as it grows, will have the power to build the will and momentum for solutions that range from inspiring innovation in textile design and manufacturing (alternative materials such as outerwear made from algae, for example) to supporting regulation and policies to installing proper filters on laundry machines - both washers and dryers - to educating consumers on clothing care habits that reduce microfiber production and extend the life of their clothing. These are solutions that will benefit all of the coastal states we visit and beyond.

Brief evaluation of the expedition:

Thanks to permitting assistance from the DoS Marine Science Research office and incredible support from the teams at National Geographic Society and Lindblad Expeditions, as well as the guests and crew onboard the *NG Endurance*, all of the scientific and outreach objectives were met.

Ultimately, 55 total samples were taken; two one-liter samples and one air pump sample from 19 locations over the expedition route. The samples were filtered and transferred to slides onboard the *NG Endurance*. Full slide analysis was conducted at Northumbria University and the data were analyzed by our team in Vermont.

Guests onboard the *NG Endurance* enthusiastically assisted with the water collection. Some helped with filtering and all participated in presentations, workshops and discussions led by PI, Rachael Miller. The final report (below) is currently free and publicly available as an interactive StoryMap at: https://bit.ly/CSIfortheOceanSubarctic2024

To date, Rachael has given one live webinar to discuss the results of this as well as other National Geographic - Lindblad Expeditions voyages on which the same science was conducted and more are planned.

The data from this expedition will be added to the growing global dataset as well as used as part of messaging campaigns, presentations and future publications all with the goal to use what we are learning by conducting this science and translating that data into actions that protect our precious planet and one, big, shared ocean.

We would like to say a second thank you to the teams at the Marine Science Research office as well as the officers and personnel at all of the embassies and offices who assisted us in obtaining the proper permits for this work. We appreciate your time and attention. If you have any questions, would like a copy of the data or would like to discuss anything including opportunities for Rachael to present, teach or meet with other people doing related work in any of the countries in which we visited (or beyond), please do not hesitate to contact her at: rachael@rozaliaproject.org or +1 802-578-6120.

A note about the following report:

This report is designed to be read online, ideally on a computer (rather than a small device) as it is interactive. For reporting and record-keeping purposes, it has been made into this static PDF. We highly recommend, however, that you read the report here: https://bit.ly/CSIfortheOceanSubarctic2024

If you prefer to read this PDF, please note that in order to make the report fit within the file size limits for submission through the RATS portal, the resolution has been significantly reduced. To read this PDF version in full resolution, please go to:

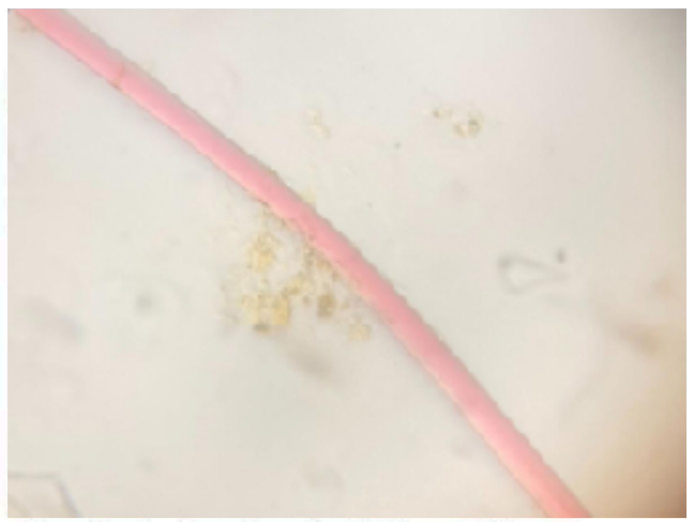
https://drive.google.com/file/d/1IO4qDWFJxbf3CZfINV6x1Q7xnoN6fqSQ/view?usp=sharing

News about huge garbage patches in the middle of oceans made many people aware of marine plastic pollution. Lately, microplastics have been in headlines. But, how global is the microplastic crisis? Our team is sailing to the ends of the Earth to learn how far microplastics have spread.

National Geographic Explorer/Visiting Scientist Rachael Miller, along with enthusiastic guests, field staff, and crew on board the *National Geographic Endurance*, collected samples from the air and surface waters along a fascinating Arctic and subarctic expedition track in order to investigate the presence (or absence) of microplastic and man-made microfiber pollution.

What are microplastics and microfibers you ask? Learn more by watching this short video.

Why this is important



A synthetic fiber found on this expedition.

Our goal is to better understand microplastic and man-made microfiber pollution - where it is and what the "it" precisely is so that it can be prevented. A growing body of evidence indicates that microplastics, microfibers in particular, pose a real threat to creatures throughout the marine food web. These particles are present in the air, water, sediment and soil and their tiny size (less than 5mm in all dimensions) makes them easy to ingest and inhale for creatures of all sizes.

Examples of documented impacts on marine life:

- Inflammation
- Food dilution (e.g. little plankton bellies filled with textile fibers instead of food)
- Behavior changes

- Mortality

Further research shows the presence of microplastics throughout the human body (including hearts, lungs, guts, blood, testicles and brains) via ingestion and inhalation, with studies published this year indicating associations between the presence of microplastics and severe illness.

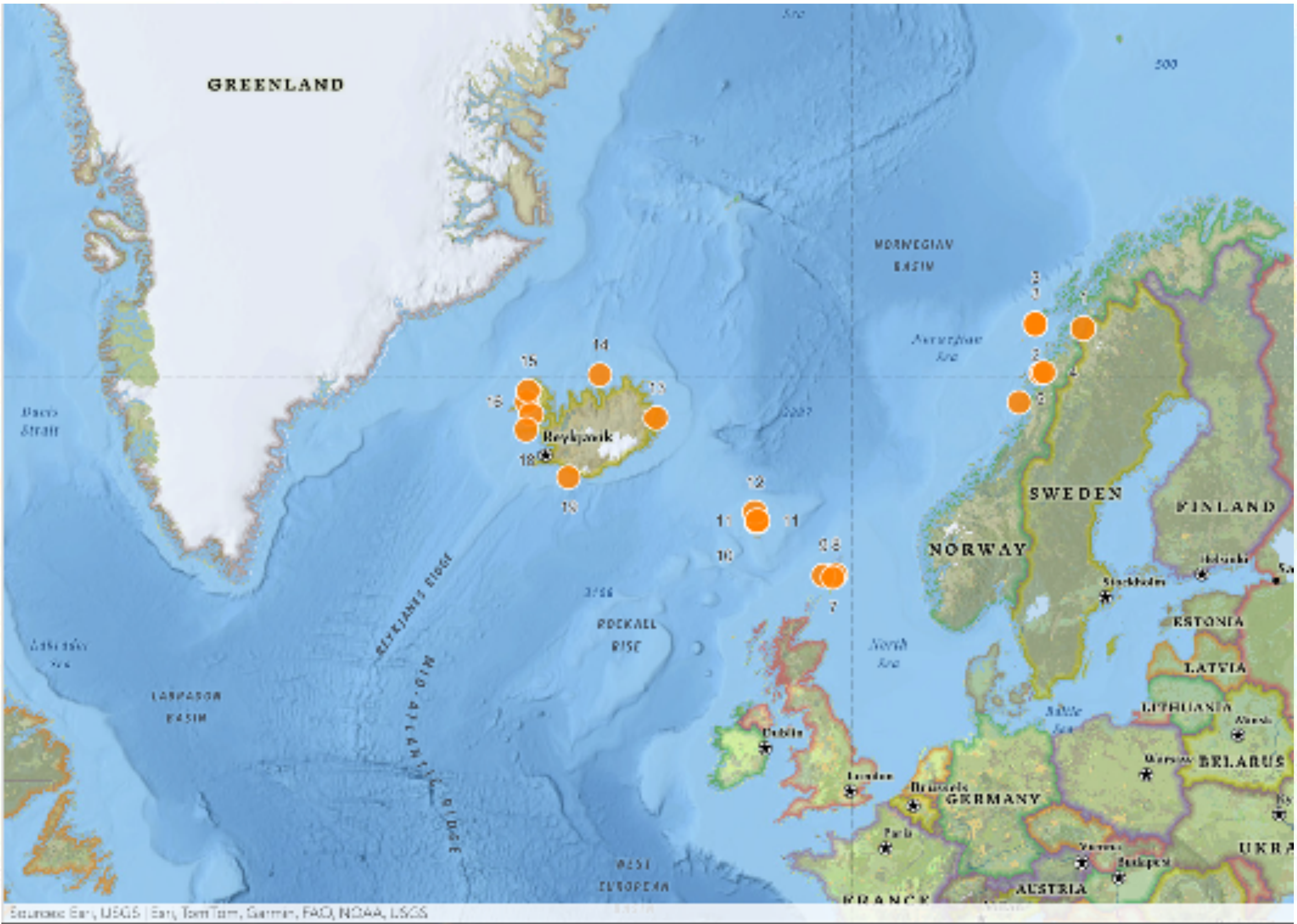
Examples of health impacts on humans:

- A disrupted gut microbiome/digestive issues were correlated with microplastics in the human digestive tract (*Pinto-Rodrigues, Science News March 23, 2023, Nissen et al. Environment International, 2024*)
- Microplastics in testis indicated a potential of reduced fertility (*Hu et al. Toxicological Sciences, 2024*)
- Microplastics in arterial plaque increased chance of stroke or heart attack (*R. Marfella et al. New England Journal of Medicine, 2024*)

Puffins of Grimsey Island, Iceland

Add to this growing body of knowledge the fact that everyone who wears and launders clothing is inadvertently involved in this pollution and the result is a rapidly growing urgency to address microplastic and microfiber pollution. Our expedition data, in populated as well as remote parts of the planet, are already pointing to actionable information while indicating solutions and opportunities for innovation. But to be most effective, we need to learn more. Join us as we share the experiences and results from the mountainous fjords of northwest Norway, the beaches and cliffs of the Shetland Islands, the striking green and rock landscape of the Faroe Islands and the puffins, whales, lupin, volcanoes and waterfalls of Iceland!

Note: We recommend using a tablet, laptop or desktop monitor for the best viewing experience.



Methods

To measure the presence of microplastics and microfibers we collected 55 samples in total; two one-liter water samples and 1 air pump sample from 19 locations from latitude 69° N in Tromso, Norway along the west coast fjords of Norway to the Shetland Islands, Faroe Islands and along a 3/4 circumnavigation of Iceland (expedition track).

The samples were filtered and transferred to glass slides using Easylift Tape while onboard the ship. The slides were analyzed at Northumbria University using a polarizing light microscope. **Scroll right for more details.**

Note: Hover your cursor over the orange dots for additional details about each sample location. You can zoom in and click to drag and explore our sampling locations.

Sample Collection

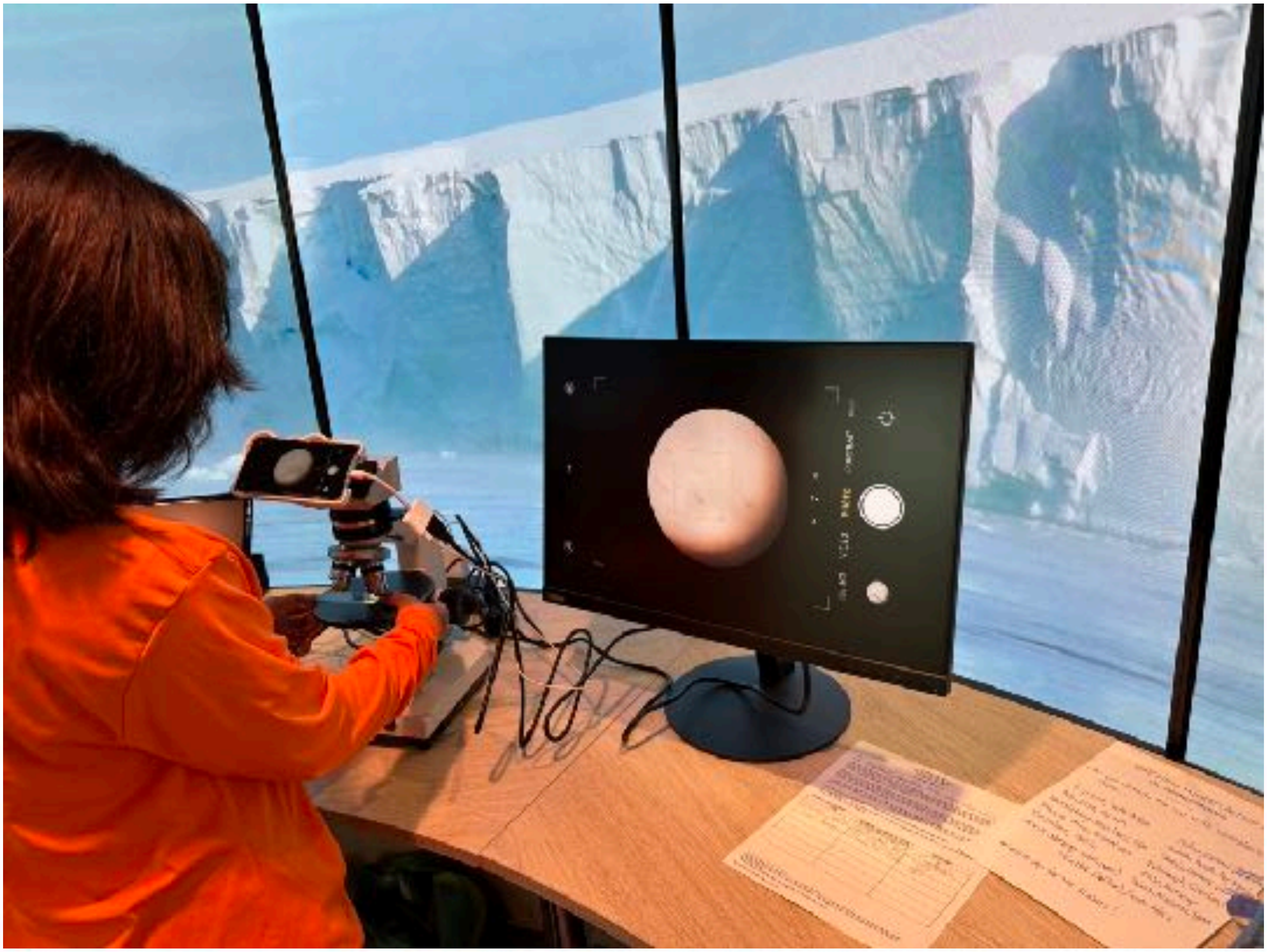
The surface water samples were collected using a metal bucket, decanted into silicone sample bags. All equipment was triple-rinsed in the sea water to remove any contaminant particles before securing the real sample.

The air pump was affixed at the bow on the Bridge deck of the ship (deck 7) and left to pump 10L/min for between 112 and 318 minutes.

Sample Processing

The water samples were filtered in the Science Hub on deck 8 of the *Endurance* with the help of guest volunteer, Jacqui Cauilan and cultural specialist Karin Murray-Bergquist. A tape lift was executed on all water and air samples in order to fix them to glass slides for preservation and analysis.

For both water an air samples, the volume filtered was recorded and the results are reported using the units: anthropogenic (manmade) microparticles (AMPs) per liter.



Analysis

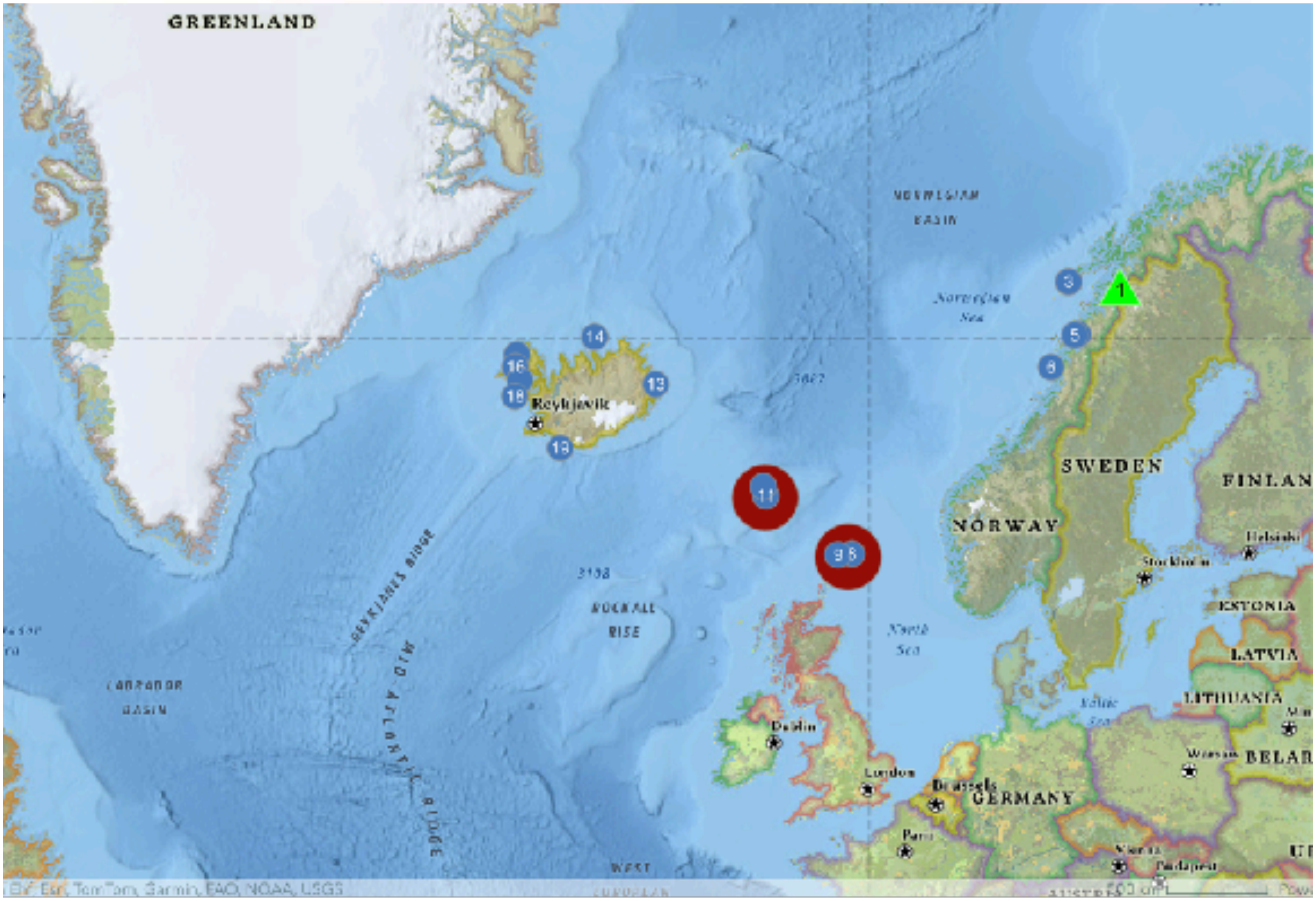
Analysis was done using a polarizing light microscope to collect morphological data as well as obtain material IDs on fibers. While some slides were analyzed onboard to give us an idea of what was in the samples, all of the samples were sent to Northumbria University for full analysis. PhD candidate Emily Donaghy performed the analysis that included recording six morphological details, including material ID, of all particles of interest on the slides.

Reducing Contamination

One of the biggest concerns with microplastic science, especially when anthropogenic microfibers are included in the investigation, is contamination. In order to control contamination, several actions were taken including triple rinsing the sample bag, noting clothing worn by samplers, and minimizing exposure to the air during processing. Air controls were taken in the Science Hub each day samples were exposed during filtration and tape lifting.

Furthermore, samples were taken of items that could contribute to potential contamination, such as expedition jackets, orange shirts worn during processing, and carpets. If there was a match between a particle of interest on the sample slide and either a known textile from the ship or a fiber from an air blank, that particle was considered contamination and not pollution.

Results



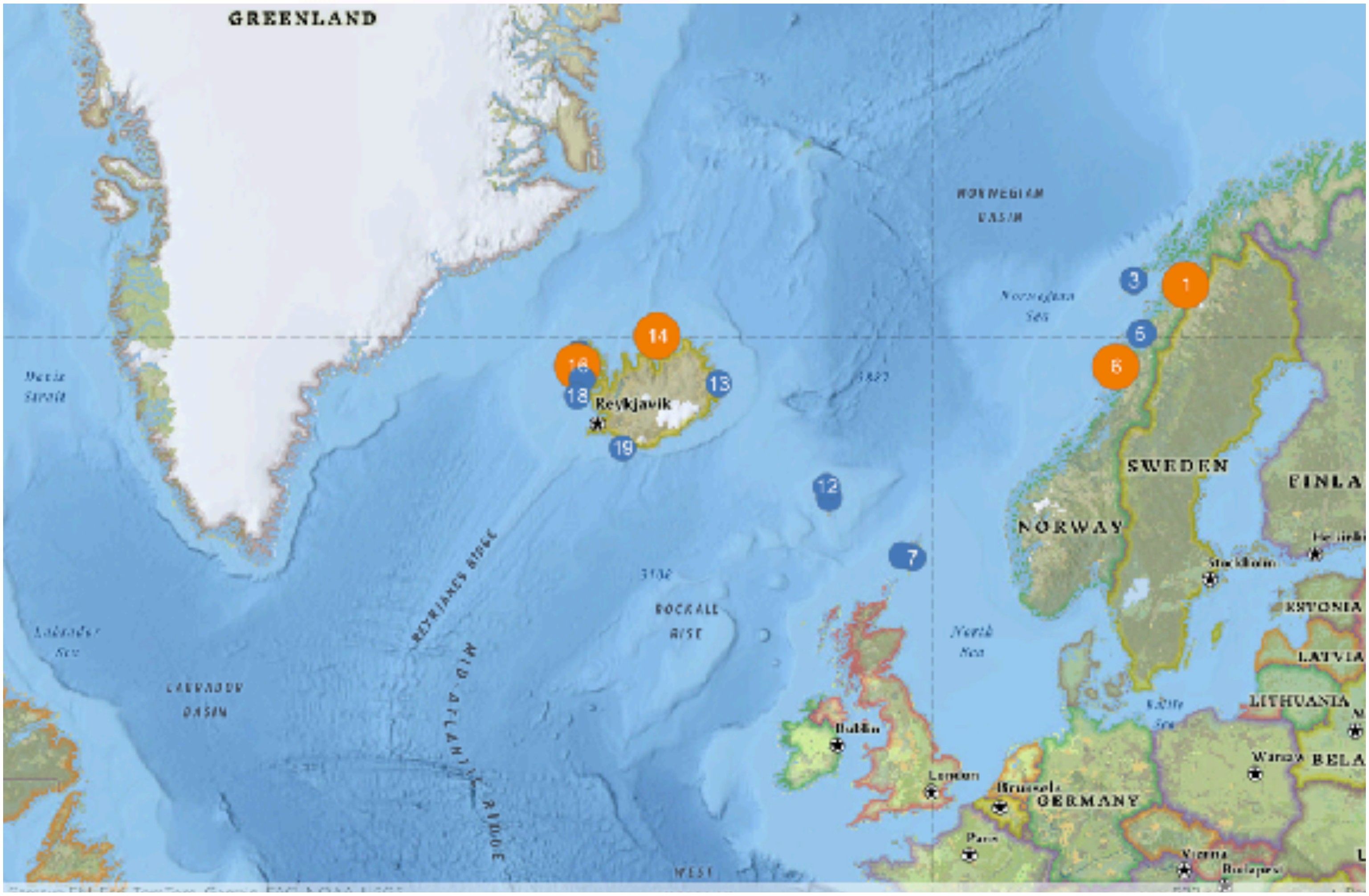
Above: Concentration

Hotspots: water and air

For our primary analysis, we looked at distribution with an eye toward finding microparticle hotspots (by using z-scores[1]). This indicates whether a region has evenly distributed microparticle pollution and helps us zero in on areas for future study.

There were two primary hotspots in the water, locations 7 (Lerwick harbor) and 10 (Torshavn port), and no secondary hotspots. In the air, there were four secondary hotspots and no primary hotspots. These results indicate there was a much

Results



Above: Hot spots

Hotspots: water and air

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There were two primary hotspots in the water, locations 7 (Lerwick harbor) and 10 (Torshavn port), and no secondary hotspots. In the air, there were four secondary hotspots and no primary hotspots. These results indicate there was a much greater range in the number of AMPs found in the water than the amount found in the air.

Note: Move the white centerline left or right to compare the water (left) and air (right) hotspots.

[1]Z-scores are related to the difference between a location's concentration and how many standard deviations it is from the mean. If two or more, it is a primary and if 1-1.9, then it is considered a secondary hotspot.

Potential Sources: Ports

The water pollution hotspots, locations 7 and 10 are both samples taken in busy harbors, particularly Location 10, Torshavn, the primary port in the Faroe Islands.

Considering the proximity to potential sources and the fact that these ports are dead ends in that rather than the water moving past (like it does for a coastal sample location), it must come in and out of the harbor, this is a result that could be expected. It strengthens the importance of ports taking preventative measures to contain potential contaminants and trash.

Air pollution relatively even despite diverse locations

While the water hotspots stood out from the others and occurred at busy ports, the air hotspots occurred in some particularly diverse sampling situations from remote Grimsey Island off the north coast of Iceland to Isafjordour where we had 3 cruise ships docked within 4 boat lengths of our ship. Furthermore, the fact that there were only secondary hotspots and the ratio of categories to particles was similar to what we found in the Arctic and Antarctic, indicates that while we saw significantly more micropollution in the water, the air along this expedition track appears to remain relatively lower and similar to what we found in much more remote places of our other expedition tracks with NG-LEX.

Potential Sources

To consider sources, we assigned every man-made particle to a numbered category based on multiple features (such as type, color, width, shape and material). Each category represents a potential source (such as a t-shirt, jacket, carpet, fishing line, etc.).

Multiple, diffuse sources; no point source

The particles we found fell into 319 distinct microparticle categories. There were 9 categories with more than one and 50 categories with only one man-made microparticle. The ratio of categories to sample locations for the air was 0.82. This indicates that we did not experience anything close to a single or point source situation but rather multiple, diffuse sources. This is a similar ratio to what we saw in the Arctic and Southern Ocean in 2023.

In contrast, the ratio of categories to sample locations for the water samples was 0.62, which is closer to what we have seen in locations with more population, such as the Hudson River (pending review) and even Hawai'i. This is a possible indication of nearer sources and therefore more particles in each category.

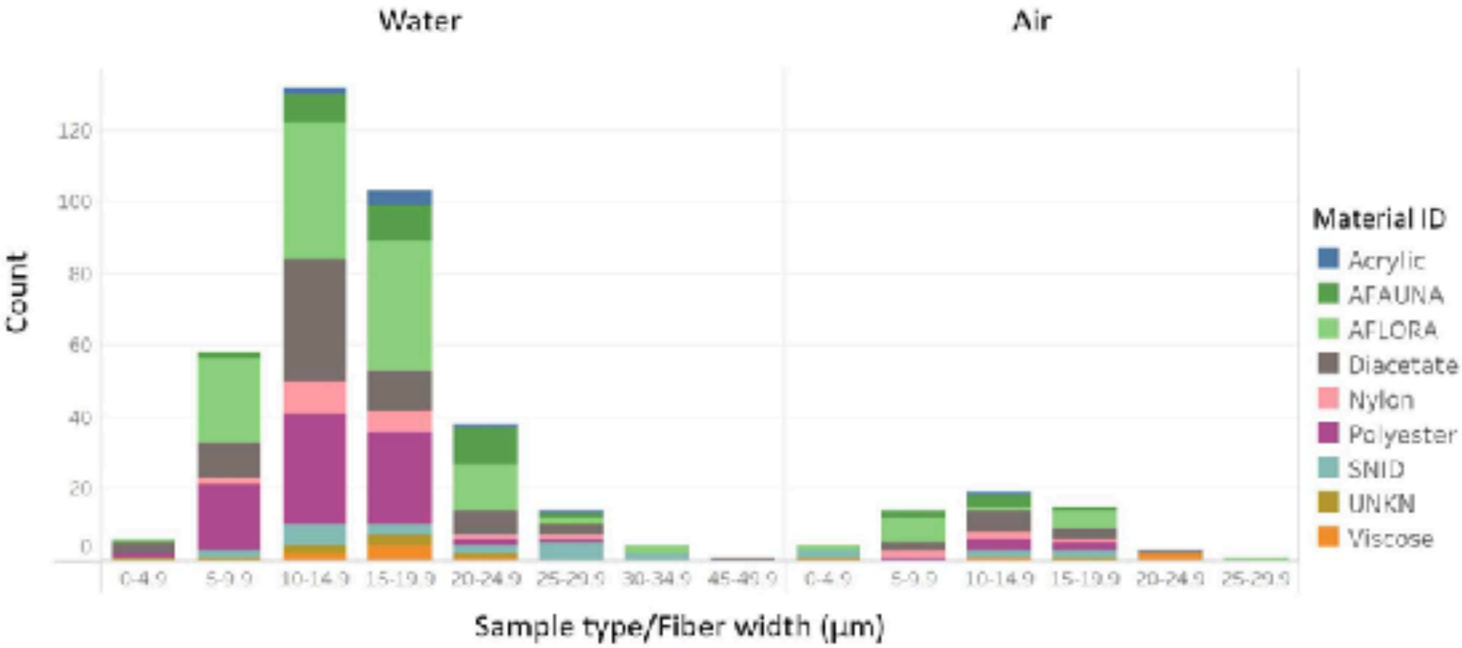
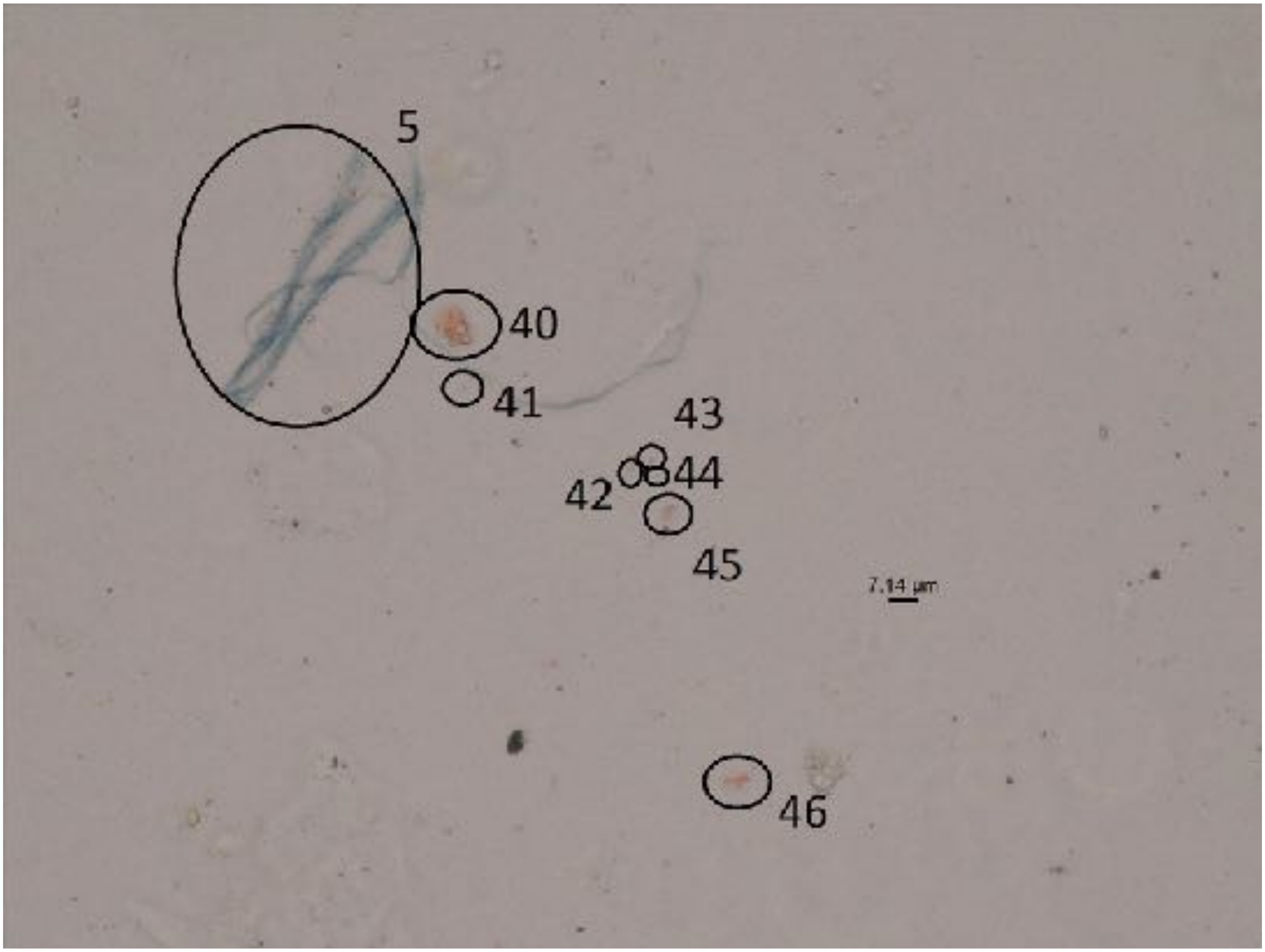


Figure 1: Fiber width and material identification (ID) in air and water.

Fiber width indicates Arctic and subarctic fibers are likely from clothing

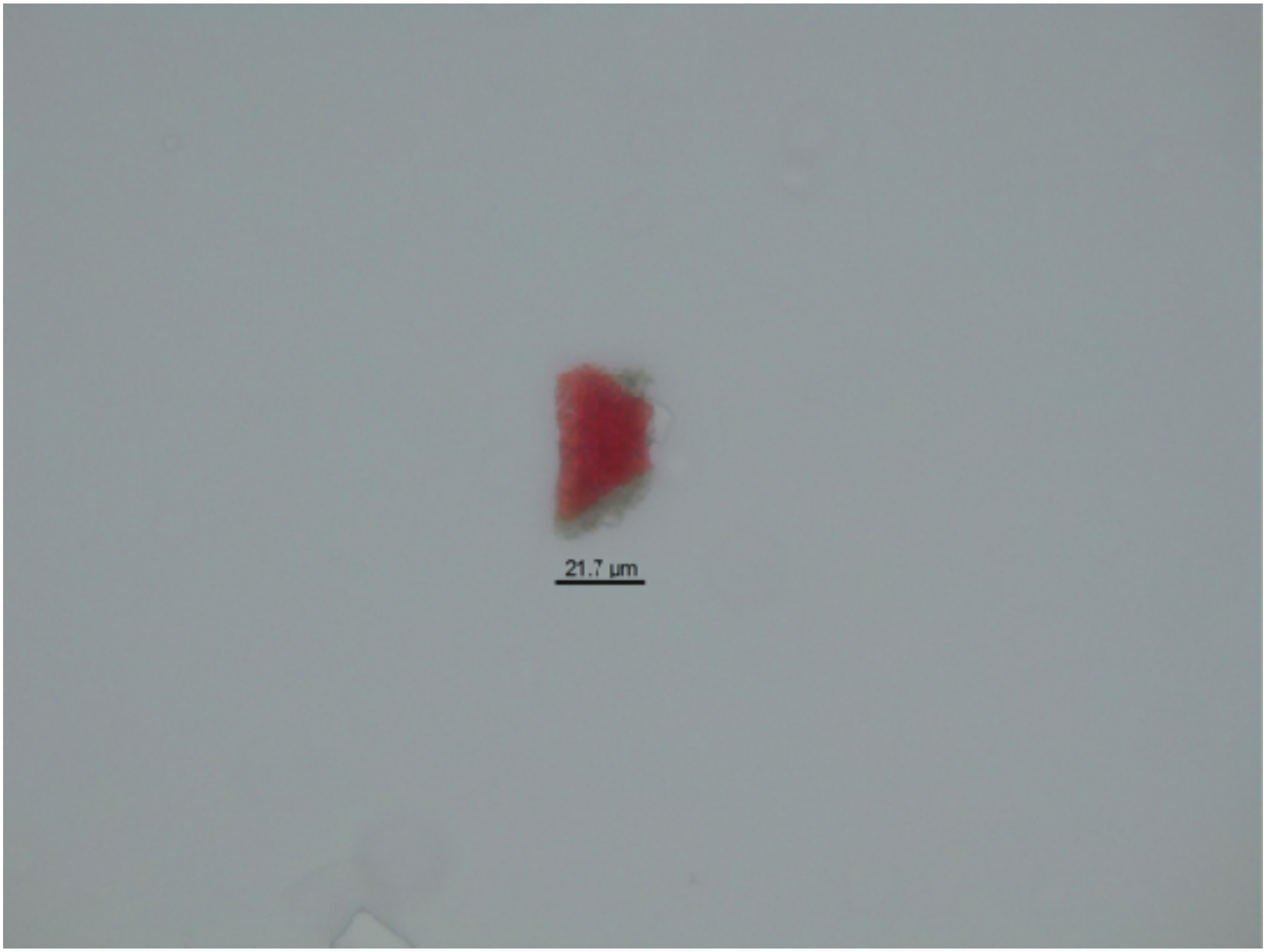
The width of a human hair is approximately 70 micrometers (µm, a millionth of a meter). As a general rule, fibers from clothing are within the 5-19.9 µm range. Fibers from carpets are usually larger than 35 µm and fibers from fishing lines are even bigger in diameter. Thus, it is most likely that a large majority of the fibers we found in the air and water along this expedition track are fragmented from clothing (Fig. 1). This fiber fragmentation can happen when clothing is worn, washed and/or dried.



Top Observations

Here are the most common and interesting microparticles we found!

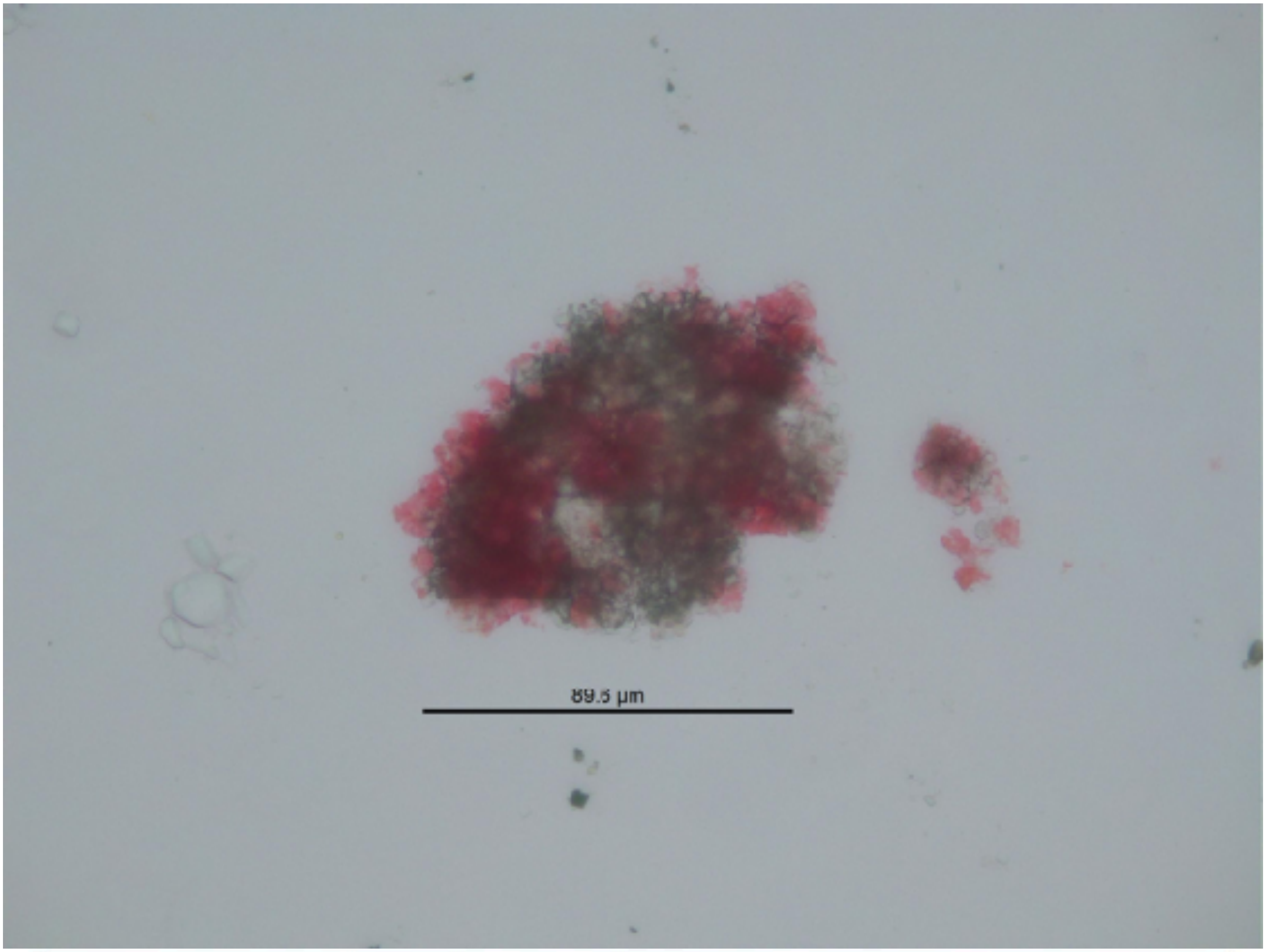
Scroll right to check them out...



Paint chips?

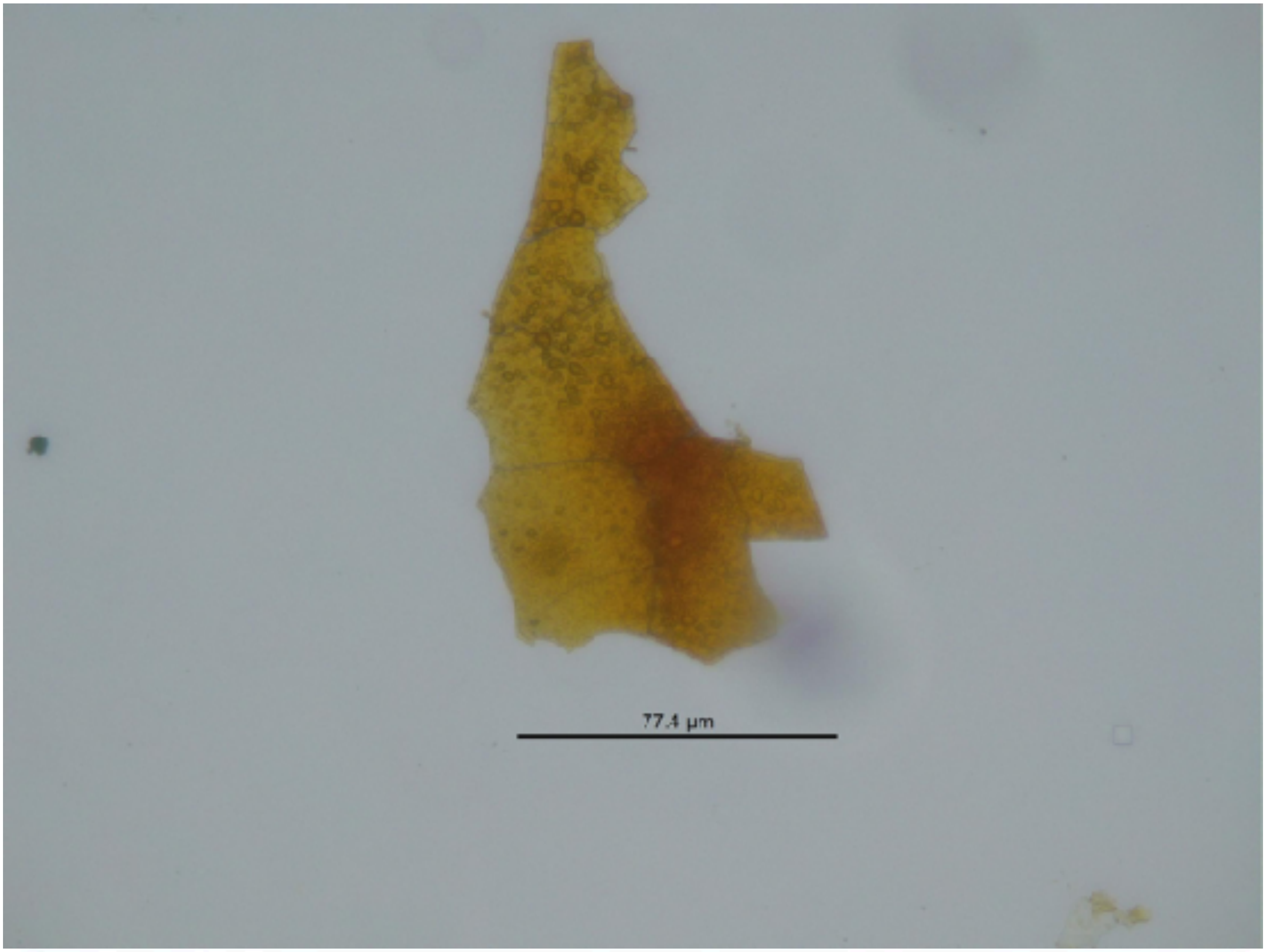
The data from this expedition had a much higher percentage of fragments than any other. Among the fragments were what appeared to be paint chips.

We found them in the water samples...



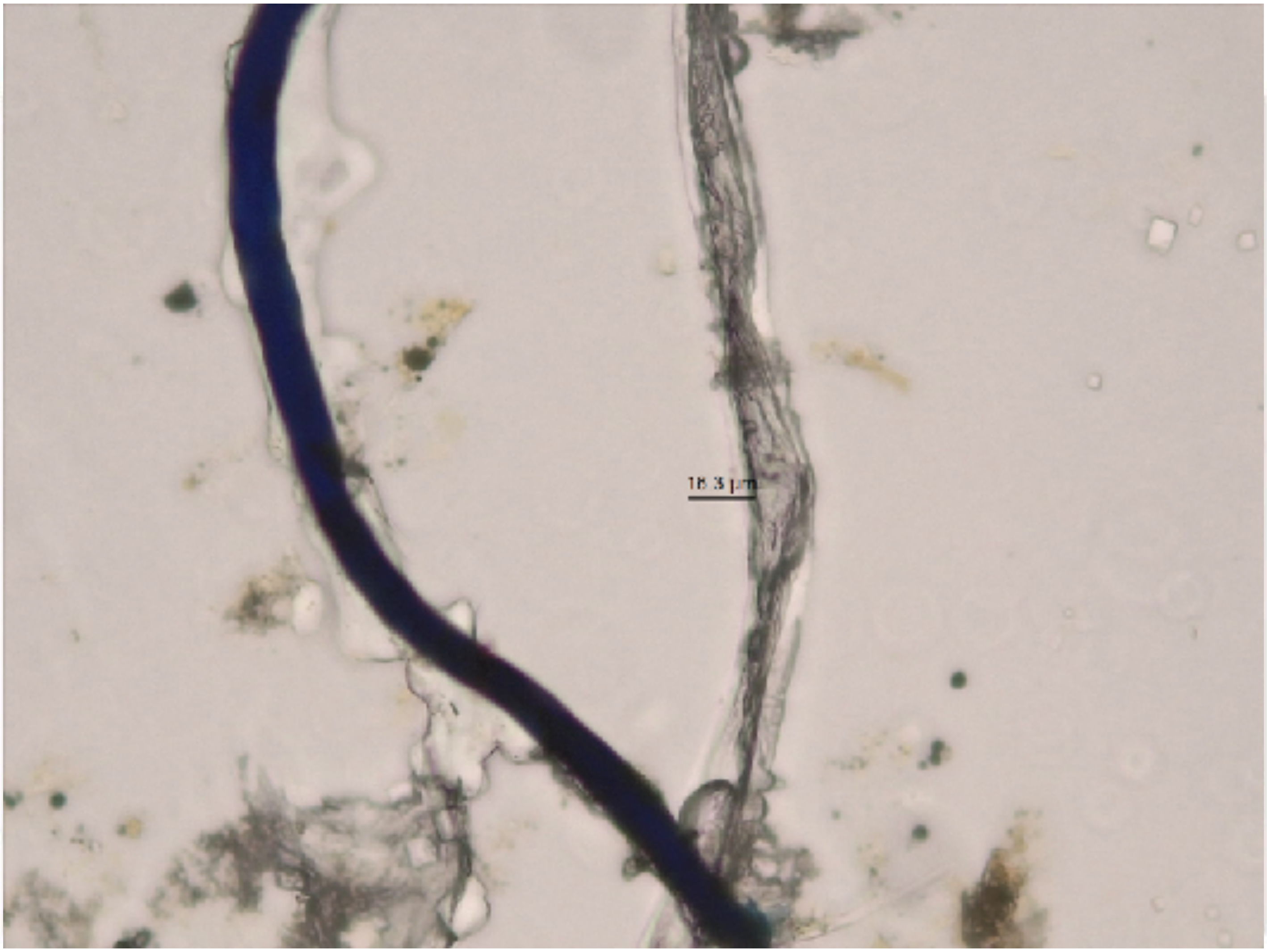
... and in the air as well such as this red fragment with biofouling.

Not only was there an abundance of red fragments, but many appeared biofouled and fractured, about to burst into many smaller particles. This indicates they have likely been in the environment for some time, allowing for creatures to colonize them and the combined elements to make them fragile.



Rust?

Part of the relatively high count of fragments also included these brittle-looking particles. It is possible that these are small bits of rust. The fact that many of our sampling locations and the two that were primary hotspots were in busy ports combined with the presence of fragments that appear to be related to vessel paint/materials indicates a need to address this potentially significant source of microparticle pollution in our global ocean.



Blue AFLORA

Among the top most common fibers found were blue, manmade/dyed plant fibers. With varying shades of blue, there were 77 total, which makes up 14.3% of all manmade microparticles. This is a very unusual result for us.

Bonus microscopic discovery from the natural world!

We have to admit that when we saw this, we had no idea whether it was natural or manmade. It is so perfect, it seemed potentially manmade. But then it is extremely tiny (1/6th the width of a human hair). Do you know what it is?

After some work with Google image we figured out that this is a **liverwort elater**. Elaters are responsible for dispersing the liverwort's spores!

The relationship between air and water

Of 319 total categories, 29 were found in both air and water; 40% of all air microparticle categories and 11.6% of water microparticle categories. This is a higher percentage of overlap between the sample environments than we have ever seen before. This indicates that the sources are likely closer than in places with less overlap.

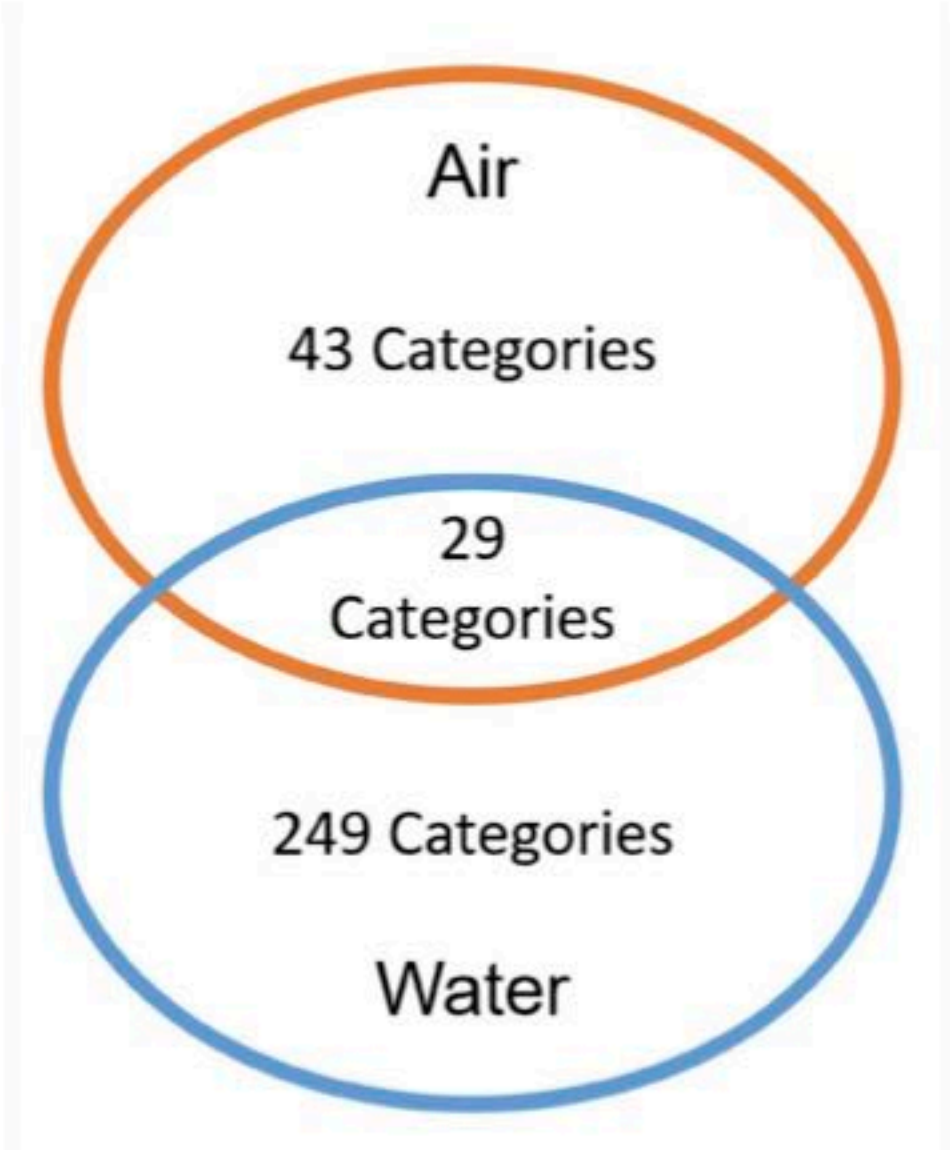
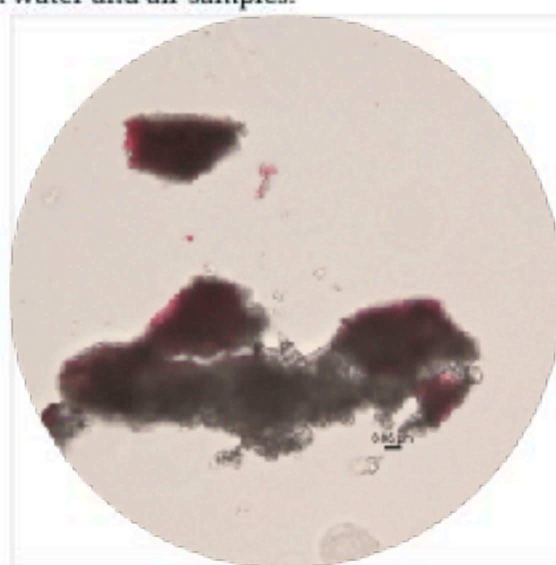


Figure 2: The distribution of fiber categories in water and air samples.

Marine growth-dating

Colonization by seaborne microscopic creatures or plants, also called biofouling, is evidence of a particle having been in the environment long enough for this growth to take place. We do not have the ability to estimate the amount of time these fragments have been in the water (that would be an excellent additional study), but this colonization does help us understand



Biofouled and fracturing fragment.

Contamination

52.3% of all particles of interest, or 589 total microparticles, were contamination contributed by our team while sampling or in the ambient air where the samples were processed onboard. This percentage may seem high and would be if we were doing our processing in a lab. However, this contamination percentage is a great improvement from previous expeditions on the *Endurance* where contamination was as much as 90% of all particles of interest. Considering our public sample processing location intended to encourage curious and lively engagement, it is relatively unsurprising and we were ready. With rigorous attention to detail, we are confident that any fiber with a similar profile as those found in our air blank controls was excluded from being recorded as environmental pollution.

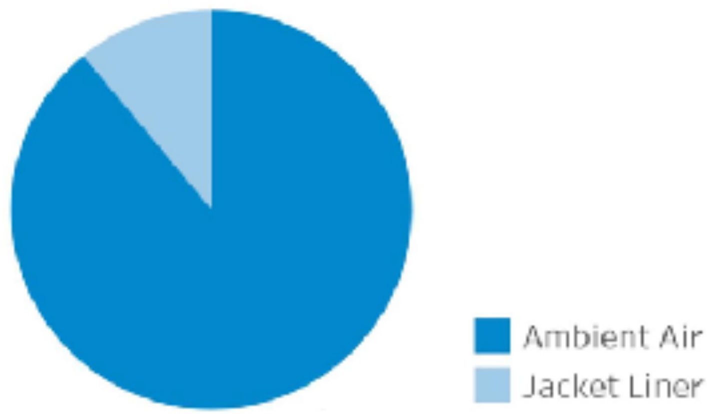


Figure 3: The sources of contamination during sample processing.

Larger Debris Observations

While the focus of our sampling on this expedition is micropollution, we are also very interested in the state of mesodebris (5mm-2.5cm), macrodebris (2.5cm-1m) and megadebris (larger than 1m) in our areas of study. Overlaying these observations with our sampling data can potentially explain the presence or transport mechanisms of both types of debris.

Here are examples of the visible micro and macrodebris we encountered starting with these fragments found on Banna Menn Beach in the Shetland Islands.

Scroll right for more...

Visible Microplastics

The beach is exposed to the northwest which is facing into the North American Current making the fairly large amount of these fragments unsurprising despite the fact that few people live near here.

Hitching a ride on currents and a jelly

This blue plastic fragment might have come from the east coast of the US because it floated to the Shetlands on the current. Or maybe it hitched a ride on this jelly?

What can we learn from observation?

Do you recognize anything that came from that vial collected on Banna Menn Beach in the Shetlands?

Fishing and consumer debris

On a very breezy day in the Faroe Islands, we happened across a small beach near a village with a beautiful kirk (church). It is clearly a highly visited site (though relatively speaking the number of people visiting the Faroes is much smaller than other places) and yet it featured the usual coastal suspects. Water bottles and fishing related debris.

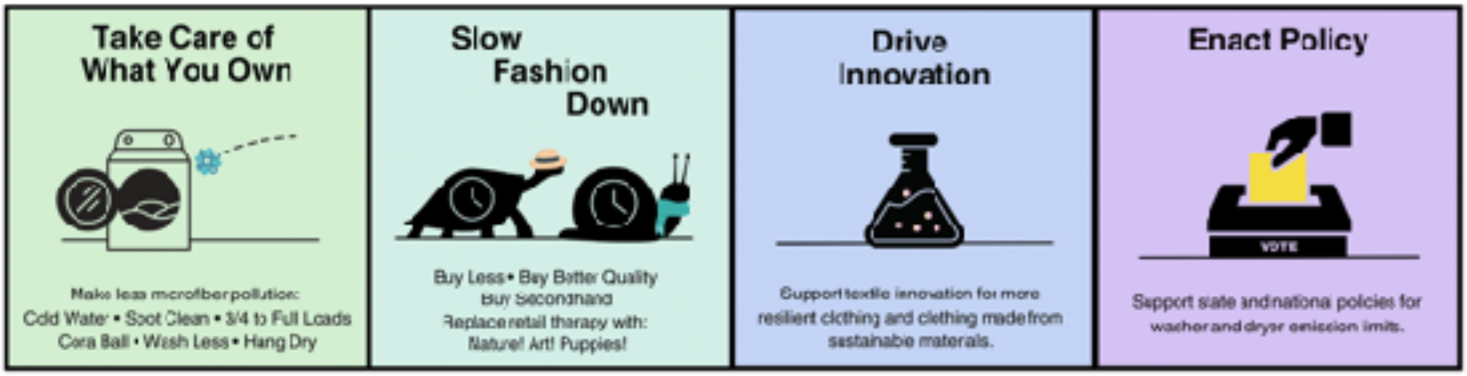
Opportunity for Future Study

In addition to comparing similar expedition tracks and opposite poles (see our Arctic 2023 StoryMap), future research in the same or similar locations but at different times of the year would produce insights into seasonal differences. Investigating microparticle fluctuations that could be influenced by weather, the presence or absence of sea ice, and changes in human activities like fishing effort and tourism would also be impactful follow-up research. Of particular interest based on the results of this expedition would be a study aiming to determine if colonization/biofouling can indicate how long a particle has been in the water and if its original can be estimated based on these growths.

Filtering and sample analysis on the *NG Endurance's* Science Hub.

Recommendations for Action

Solutions for microplastic and microfiber pollution need to take place long before the debris gets to this incredible and incredibly important part of the world. As you just learned, we primarily found microfiber pollution from fiber fragmentation in the arctic and subarctic. In fact, that is what we primarily find worldwide. We can all take action - as individuals, as innovators, as decision-makers and as policy-makers. If the list below seems like a lot, start with one item, incorporate it into your life, and then add another. These small actions will all add up to big impact!



Concerned about microfiber pollution from clothing? Solutions include everything from adapting individual attitudes toward fashion, laundering techniques, using innovations like the Cora Ball, supporting upsteam innovation to national-level action.

Click here for more information about Sustainable Laundry

In combination, these actions can result in the immediate reduction of microfiber pollution while supporting the development of long-term innovative solutions, which will, in turn, protect the spectacular creatures that call these special places home.

Shetland Island residents checking us out.

Conclusion

While the communities along this expedition track are by no means highly populated, there are more people, more ships, more industry and more recreation than along the other expedition tracks we sampled with NG-LEX. And we saw a corresponding increase in concentrations of micropollution in both the air and the water.

This expedition's findings call for action from stakeholders around the globe to make a positive change - from governments and corporations to individuals at home and exploring in nature!

Is microfiber pollution screaming out to you?

Are you a researcher, looking for a meaningful, impactful, and solutions-oriented capstone, thesis, or other project? See our Future Study page for a list of questions whose answers will speed the creation and deployment of solutions!

Acknowledgements

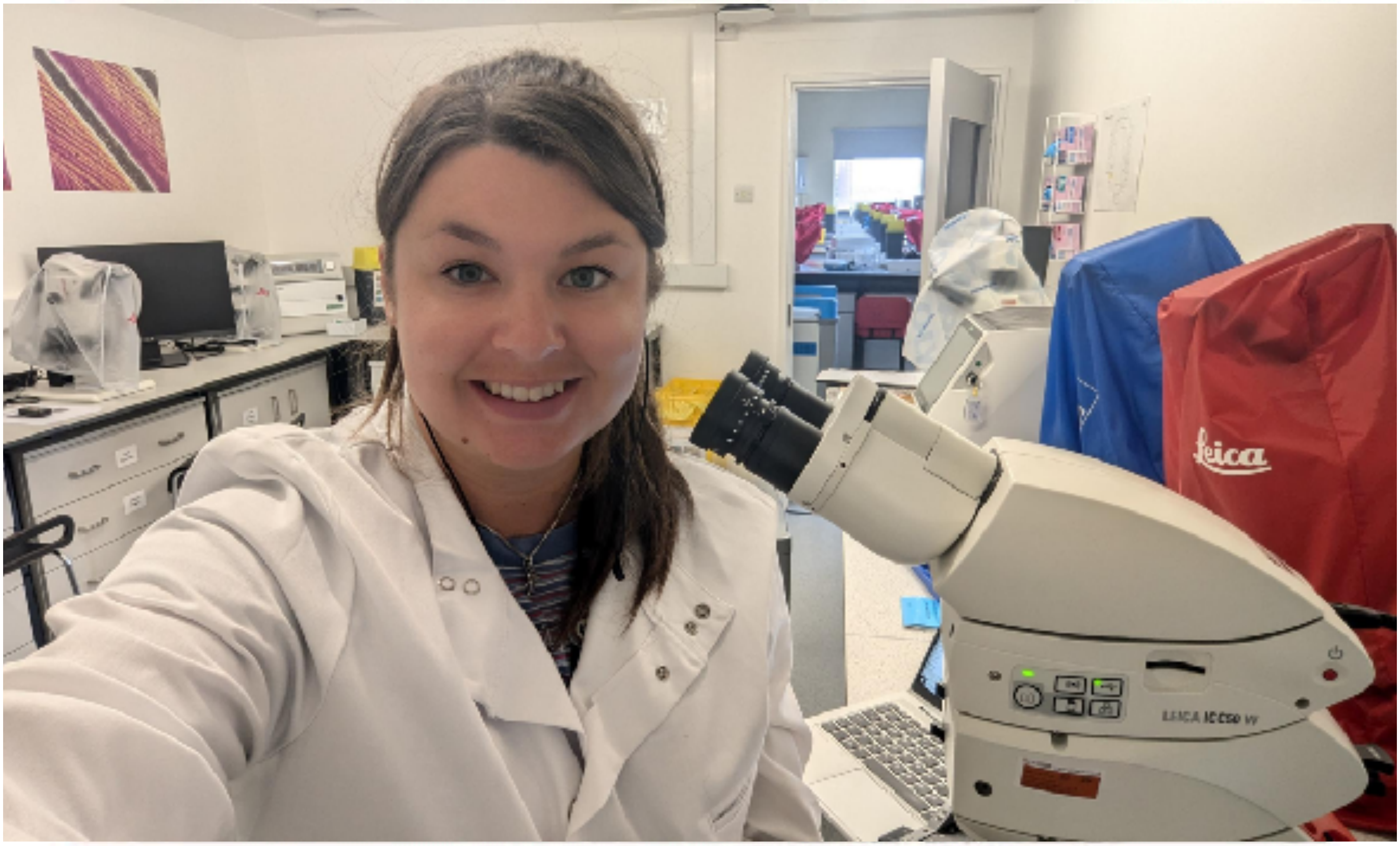
This work was made possible thanks to the incredible partnership and support from Lindblad Expeditions and the National Geographic Society, specifically the LEX-NG Fund.

Thank you to the individuals at Lindblad Expeditions and National Geographic Society who created and are driving this program forward as well as the incredible guests, crew and dazzling field staff on the Lindblad ships, the *Endurance* in particular.

For this report, we specifically applaud those on the TRYK expedition in June-July 2024. You injected your intellect, enthusiasm, skills and joy into this project and with that in the mix, we are sure to have impact! Microplastic and anthropogenic microfiber pollution may be invisible without a microscope, but all of us together are turning data into knowledge and that knowledge into action and impact - all for a clean ocean.

We'd like to say an ocean-sized thank you to everyone who has donated to the LEX-NG Fund! Your support is creating opportunities for knowledge, innovation and action that has the power to protect this breathtaking planet.

We also would like to acknowledge the team at Rozalia Project for a Clean Ocean. When Rachael founded Rozalia Project in 2009, the goal was to protect the ocean by addressing the problem of marine debris. It is incredible to see the organization grow in the capable and often sandy hands of the Board, Executive Director, staff and volunteers. Without the on-the-water team at Rozalia Project, these NG-LEX expeditions would be difficult and sometimes impossible for Rachael to execute.



We have some spectacular academic and institutional partners, specifically Dr. Kelly Sheridan, Assistant Professor in Forensic Science at Northumbria University and Research Director at The Microfiber Consortium, and Emily Donaghy, also at Northumbria University, who completed all of the slide analysis for this expedition.

Lastly, a big shout out to CSI for the Ocean development partner, Professor Claire Gwinnett and her team at Staffordshire University as well as Maija Niemesto and her team at Norrie Point Environmental Center for helping field test the methods we are now using far from the Hudson River.

Resources

Arctic 2023 National Geographic-Lindblad Expeditions on the *National Geographic Endurance* StoryMap: bit.ly/CSIfortheOceanArcticNorway2023

Southern Ocean 2023 National Geographic-Lindblad Expeditions on the National Geographic Endurance StoryMap: bit.ly/CSIfortheOceanSouthernOcean2023

Hawaii 2022 National Geographic and Ocean Exploration Trust Expedition on the *E/V Nautilus* StoryMap: bit.ly/CSIfortheOceanHawaii2022

Rozalia Project for a Clean Ocean CSI for the Ocean homepage https://www.rozaliaproject.org/csi-for-the-ocean

Rozalia Project for a Clean Ocean Microplastic Lesson Plans for formal and informal educators https://www.rozaliaproject.org/resources

Microfiber Primer for more background information about microfiber pollution https://coraball.com./blogs/ocean-protectors-blog/the-microfiber-pollution-primer

Open Access Data

The data collected on this expedition is available for free public examination and additional analysis. Please contact us at micro@rozaliaproject.org with inquiries.