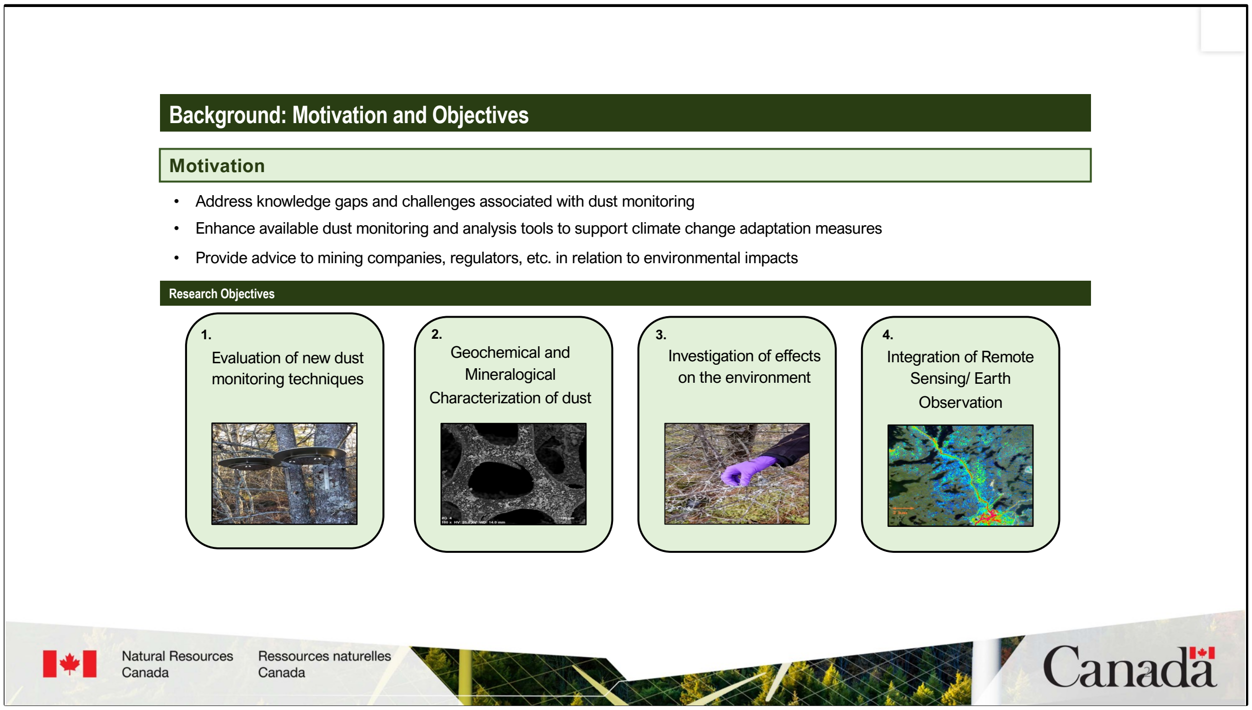
Notes: Thanks Skya for the introduction and the opportunity to speak here today. I will be presenting on behalf of a large research team, made up of colleagues from CanmetMINING and the Canadian Center for Remote Sensing, as well as collaborators from UQAT and the Canadian Forestry Service. During this presentation, I'll highlight past, present and future research projects involving dust monitoring and characterization techniques.



Notes: Our research team first started looking at dust back in 2017, after completing a literature review which highlighted knowledge gaps and challenges associated with dust monitoring- particularly challenges associated with passive dust monitoring, which I'll highlight in the following slides, and the limited knowledge on the environmental impacts of mine dust. We also found this research to be a timely topic given the implications climate change may have on dust.

Overall our research team focuses on four main areas of research, which include:

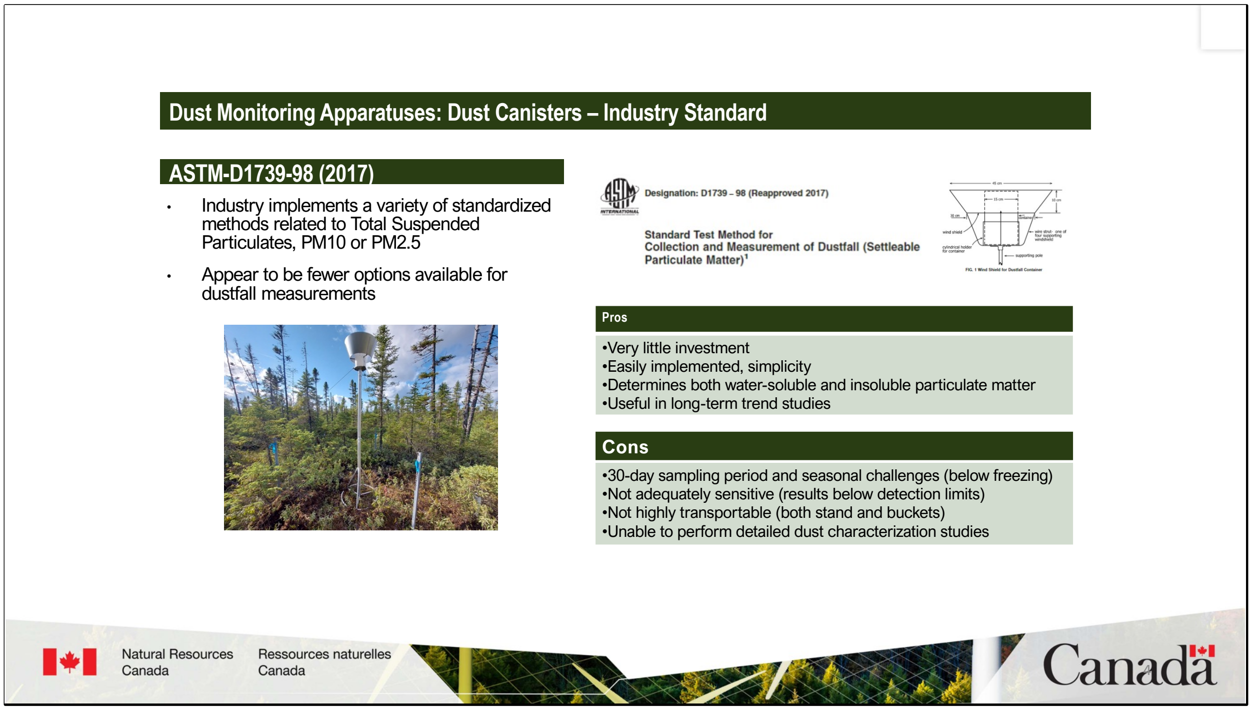
1. The evaluation of new dust monitoring techniques. Current passive monitoring techniques have various limitations, and we wanted to explore other available options.
2. The geochemical and mineralogical characterization of dust. This is essential information, such as dust composition and host phases of elements of concern, which can influence the fate and effects in the environment, which leads me to point 3.
3. Investigating the effects of dust on the environment. This can include surface water, soils, lichen, or peat, etc.. During this presentation, I will highlight how we use dust monitoring data to investigate these types of questions.
4. And finally, integrating this information with remote sensing and earth observation analysis.

Notes: Before we dive into details and some case studies, I'll give an overview of the available dust monitoring devices. Dust monitoring can be grouped into 2 categories, one being active dust monitoring where a pumping device is used to pass air through a sample. These devices are often used to meet health and safety guidelines such as PM2.5, PM10 and total suspended particulates. Results are often presented as the amount of dust within a volume of air (m^3).

In comparison, passive dust monitoring relies on kinetic energy of particulates and often occurs over longer sampling periods. The results are used to determine dustfall- which is the amount of dust being deposited over a particular area per day.

Dustfall is a particularly important as deposition on a horizontal surface is generally considered a reasonable approach used evaluate ecological impacts.

As a result, I'll be focusing this presentation on passive sampling. Additionally, I wanted to point out that the equipment and examples I highlight are based on our research and there are many different types of samplers available.



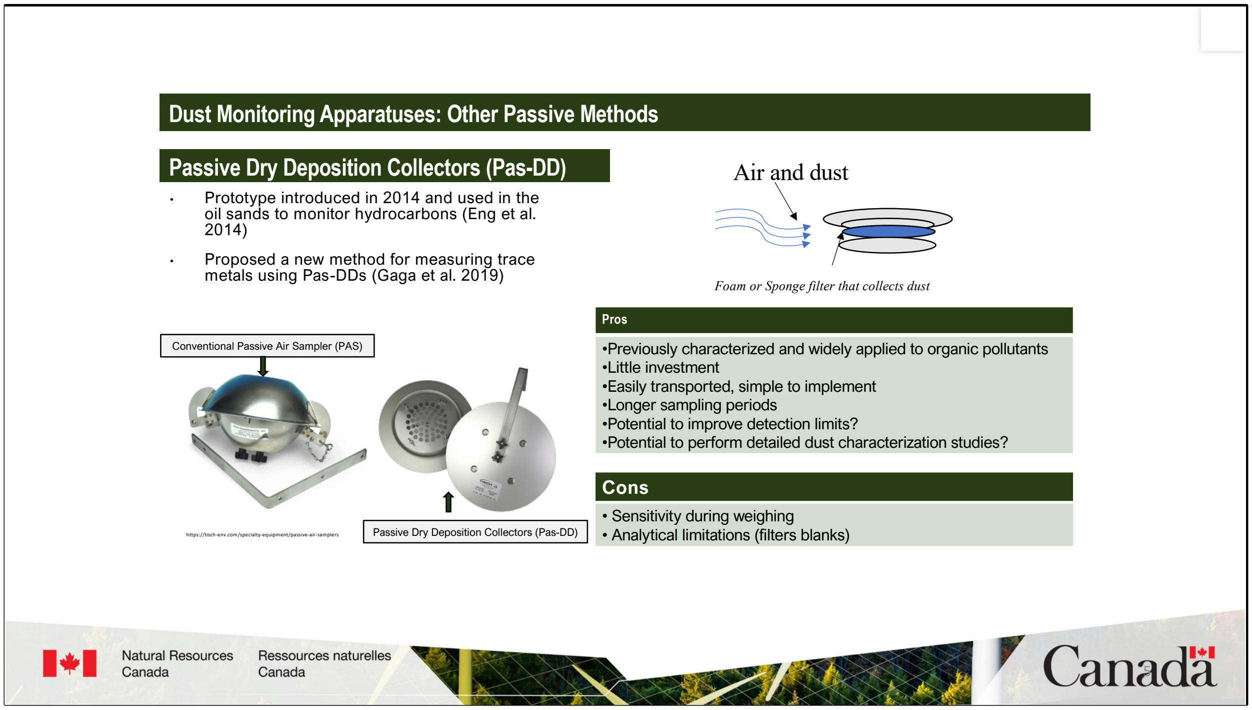
Notes: Based on literature review, it appears that the industry has various standardized methods related to total suspended particulate, PM10, PM 2.5, but there appears to the fewer options available for dust fall measurements.

We've found that the most common method is what I'll refer to as "Dust Canisters", or the ASTM method shown on the slide.

These dust canisters are left on stands and collect any settling material, including dust or precipitation, resulting in a mixture of rainwater, snow and dust which can then be analyzed.

Some of the benefits of this method include its simplicity, minimal investment and how easily it is implemented. Because the sample contains dust and precipitation, you can determine the amounts of water soluble and insoluble particulate matter. And they are most useful in long-term trend studies.

Based on our experience and feedback from industry, there are various limitation with this method including the 30-day sampling period, which requires access to the sampling site year around, and limits the amount of dust which can accumulate in the sample. This can result in dustfall measurement being below detections limit. Additionally, seasonal challenges arise particularly below freezing where snow and freezing of the solution can cause uncertainties. The stands and buckets are not very transportable for more remote locations, and you are unable to perform detailed dust characterization studies, such as different mineralogical approaches, due to the dust being mixed with precipitation.

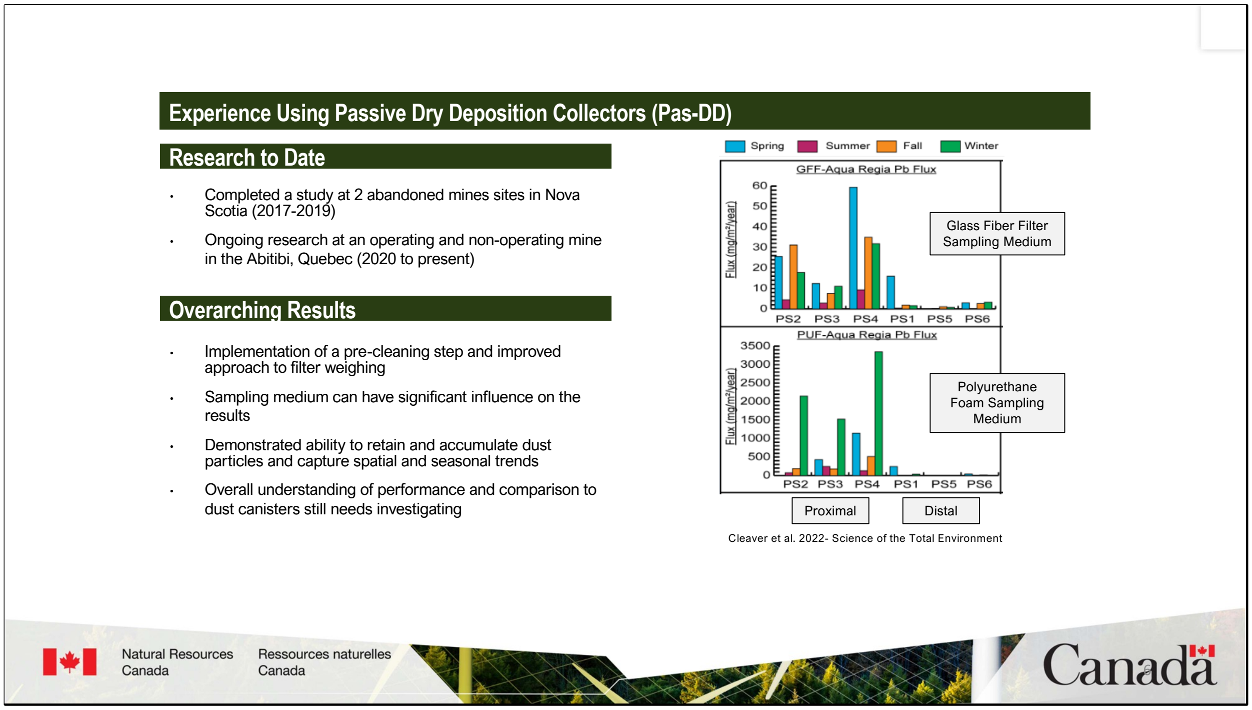


Notes: With that in mind, there are a few other passive methods presented in scientific journals, a common one being "Conventional Passive Air Samplers" which are the domes pictured on the left. Air travels in between the lower and upper dome and entrains particles on a filter- however due to the dome-shaped nature it tends to only collect finer particles, instead of larger particles that would be deposited onto terrestrial surfaces.

In 2014, a proto-type referred to as "passive dry deposition collectors" was introduced, originally for monitoring hydrocarbons in the oil sands, which are picture to the right. Recently in 2019, Gaga et al. proposed a method for measuring trace metals using the Pas-DD.

Based on our experience using the Pas-DD and the literature, some benefits include the minimum investment needed, easy transportation and implementation. But the major benefit of this method is that the dust sample is not incorporated into a mixture with precipitation. This allows for longer sampling periods (for example you could leave the sample up for 3-4 months). By leaving the sample in the field longer, this may potentially improve detection limitation concerns. Additionally, the filters provide the potential to perform detailed dust characterization studies. Looking into these possibilities is what our research tries to address.

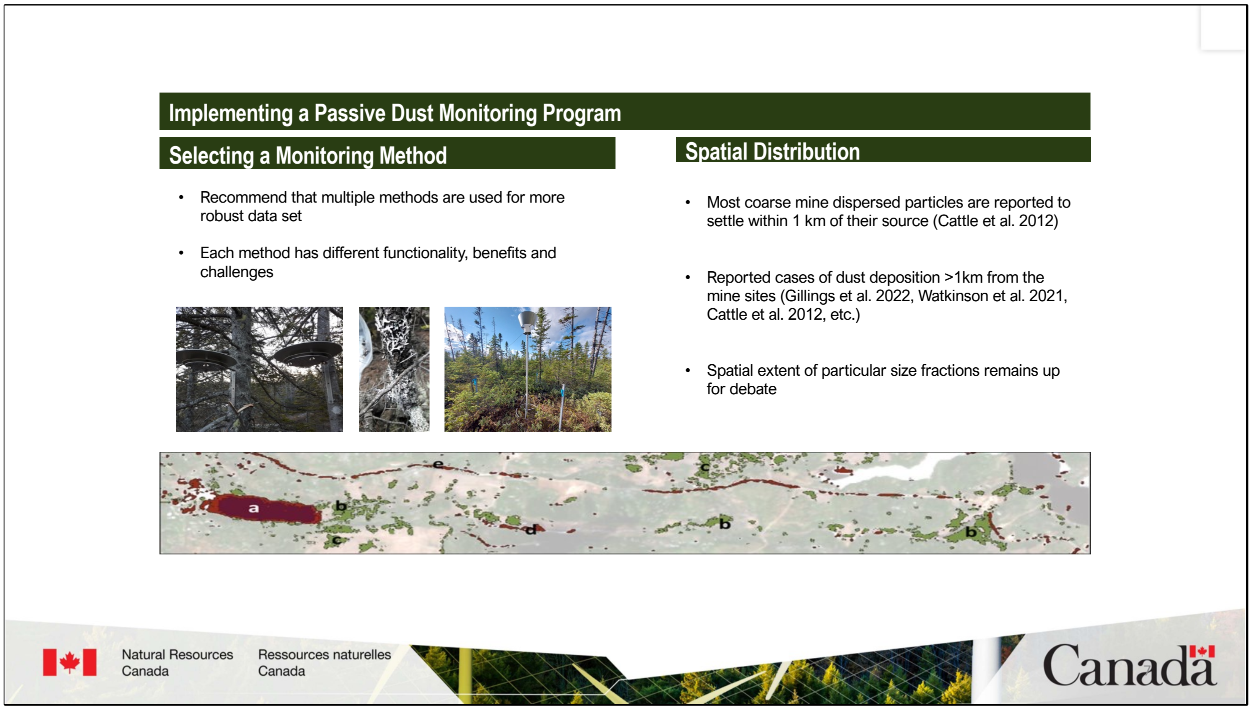
Some challenges with this method include sample preparation as the filters must be cleaned and weighed before being deployed.



Notes: This slide is to summarize our experiences testing the Pas-DDs. We have worked at 2 abandoned mine sites in Nova Scotia. And since then, we have started an ongoing project at 2 mines in the Abitibi region. We are also currently planning future work in the Arctic.

Based on these projects, some of our overarching results to date include:

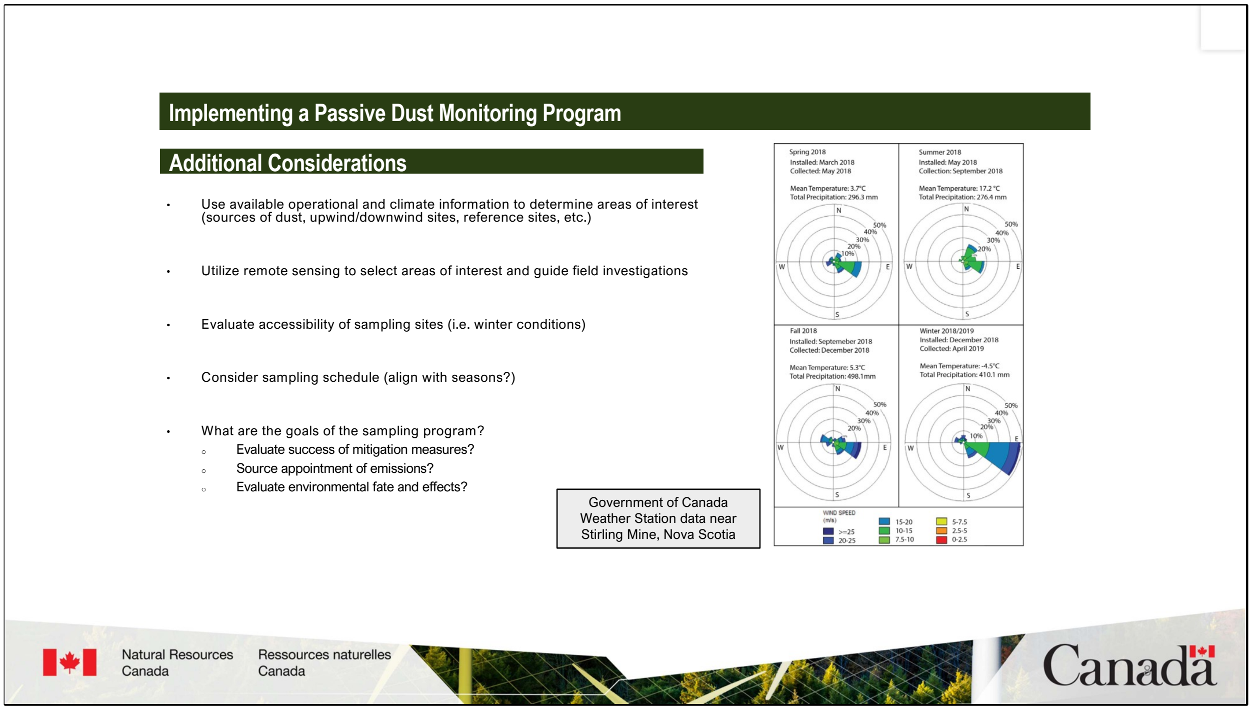
- The importance of implementing a pre-cleaning step and improved approaches to filter weighing. During our first study, unused filter blanks had high levels of metals and filters weight were inaccurate due to sensitivity to humidity, these limitations have been addressed within our current project
- We have observed that the sampling medium can have a significant influence on dust deposition results. The graph to the right compares lead flux rates for glass fiber filters in the top and polyurethane foam filters in the bottom, by looking at the y-axis you can see the foam filters accumulated dust much more efficiently. This is because dust could be re-suspended from the glass fiber filters due to smaller pore sizes. We now use the foam filters, as a result.
- We've also shown that the Pas-DDs can be used to track spatial and seasonal trends. In the image the first 3 sets of bar graphs (PS2,3,4) are proximal to a tailing impoundment area, while the other 3 are more distal and the dust deposition clearly reflects this. The colours of the bars represent the different seasons and the lower amount of dust in the summer (purple) was clearly observed, we believe this due to freeze drying in the winter and higher wind speeds. Overall, the Pas-DD capture spatial and seasonal trends efficiently and as expected.
- Our ongoing work hopes to continue to evaluate the abilities of the Pas-DD and include a comparison to the dust canisters which wasn't completed during our previous work.



Notes: From these research projects, we've learned some useful tips when it comes to planning and implementing a passive dust monitoring program.

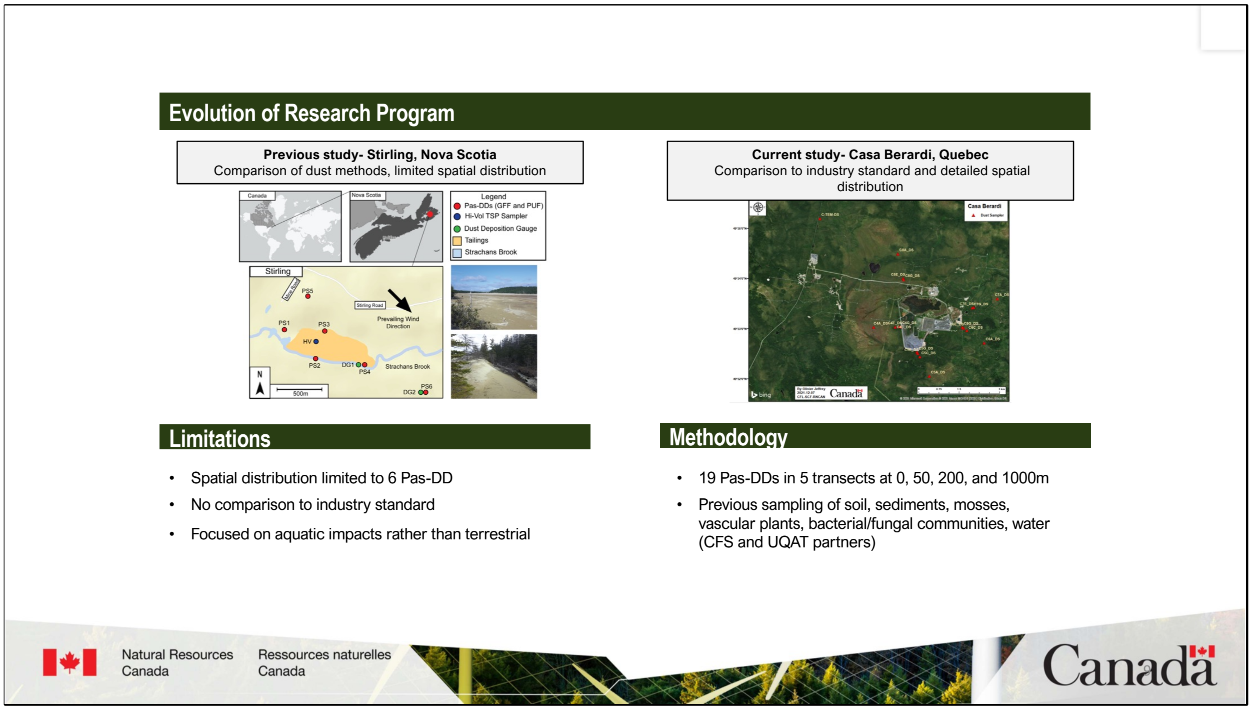
The first question we often get asked by interested parties is what monitoring method to select. And while we have seen a lot of benefits associated with the Pas-DDs, we have seen benefits in other techniques we have tested including the dust canisters, lichen, and remote sensing. Based on our comparison study in Nova Scotia, which are pictured on the slide, we found that each method has different functionality, benefits and challenges. As a result, using multiple methods produced a more robust data set which we were confident in.

We also commonly get asked about reference sites and how far can dust travel. And while most coarse mine dust are reported to settle within 1 km, which we have observed as well. There are reported cases of dust deposition >1 km and in general the spatial extent of particular size fractions remains up for debate and is not well understood. For example, Giant mineral dust particles (>75 µm) have been observed travelling great distances (>10,000 km) (van der Does et al. 2018), so there is still a lot of research needed in this space.



Notes: Other considerations when planning a program, include utilizing available operational and climate information to determine areas of interest, such as sources of dust, both upwind and downwind sites, and proper reference sites. The image to the right is an example of some background information such as wind rose diagrams which assisted us in choosing sampling locations. We've also found that using remote sensing to select areas of interest and guiding field investigation is a useful tool to ensure your dust program properly captures the extent of the dust.

Other challenges include accessibility of sites in different seasons, what your sampling schedule will be and the goals of the sampling program.

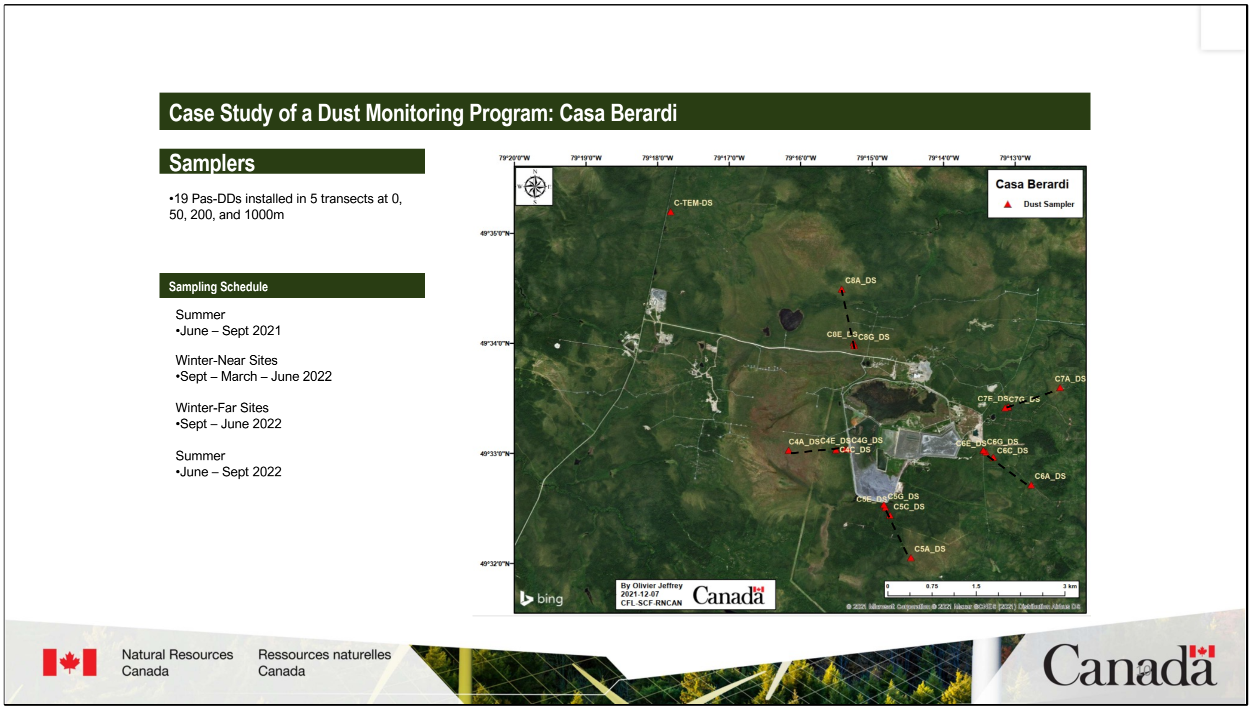


Notes: We have implemented these lessons from Nova Scotia to a case study at Casa Berardi mine, which is an operating gold mine in the Abitibi region. This study is in collaboration with Christine Martineau (Canadian Forest Service) and Nicole Fenton (UQAT).

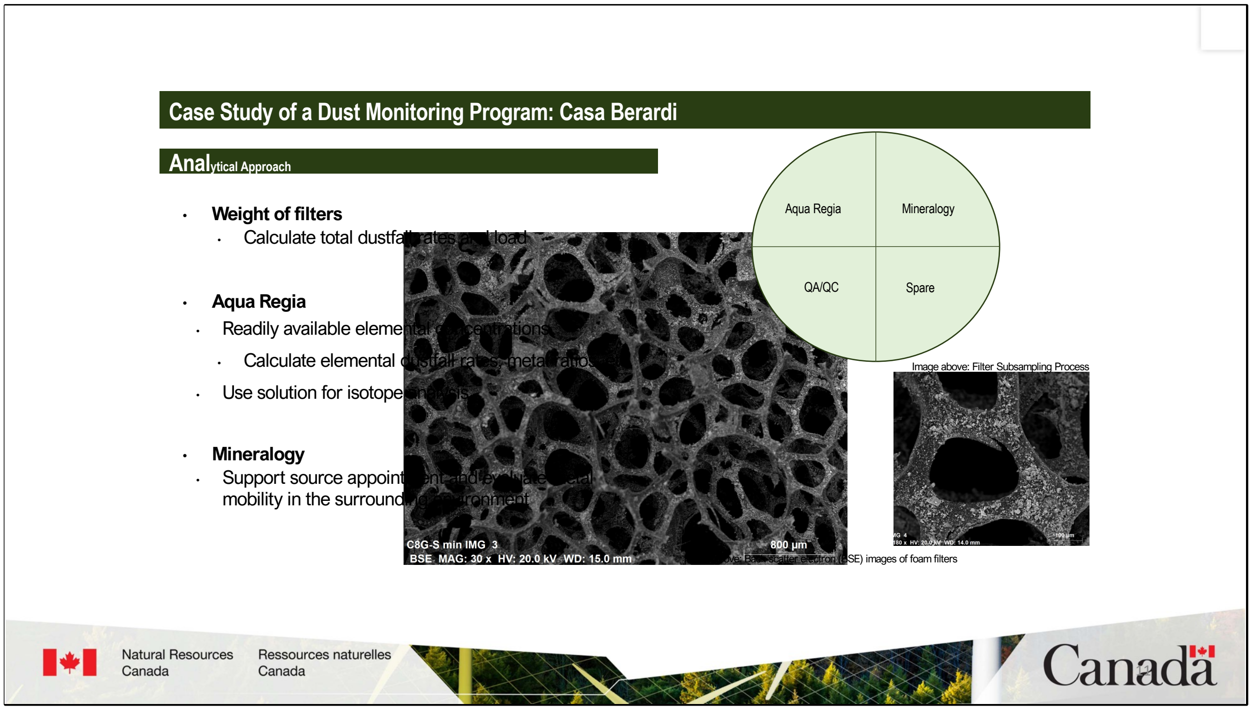
The objective of this study is to investigate source appointment and evaluate spatial trends.

The left image illustrates a set-up in Nova Scotia, the main goal of this research was to compare different methods, evaluate impacts to surface waters and involved a very limited spatial evaluation, as shown.

In comparison, the image on the right illustrates the current set up at Casa Berardi which includes 19 Pas-DDs in 5 transects, allowing for a much more detailed spatial evaluation. The transect were set-up previously by Nicole and Christine’s teams with corresponding soil, sediment, moss, vascular plant, fungi/bacterial samples. A strength of this research is the variety of samples taken at the same location, which allows for the comparison between sources of contaminants and effects on the ecosystem. Additionally, we previous didn’t compare the dust canisters and Pas-DD in Nova Scotia, so that is also part of the study at Casa Berardi.



Notes: So, as mentioned this study involves 19 samplers in 5 transects. Our sample schedule included the summer of 2021 (June to Sept), Winter (Sept to June)- as we were limited with COVID. However, we were to switch some of the closer sites in March, and another set of filters this past Summer in 2022.



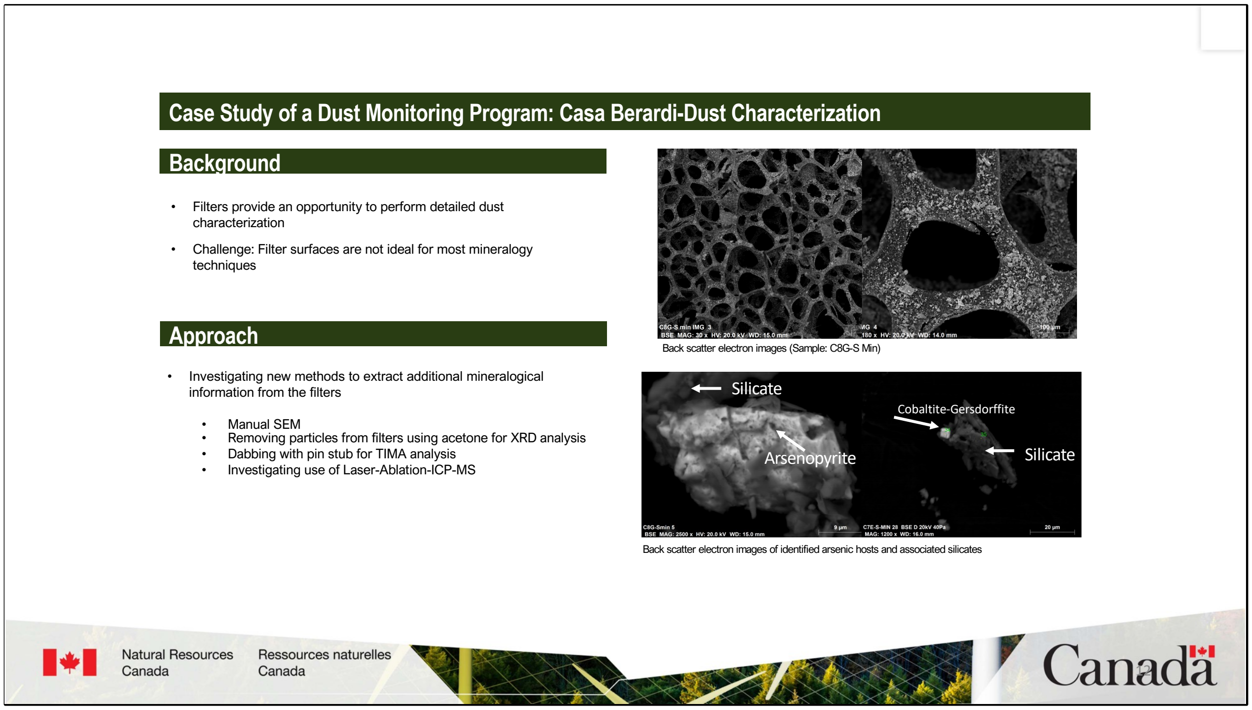
Notes: Once we collect the filters, we use a variety of different analytical techniques to characterize the dust.

First, we weigh the filter- both before and after deployment-which allows us to calculate total dustfall rates and load.

We then cut the filter into quarters for different analysis. One quarter goes towards aqua regia digest- which provides us with readily available elemental concentrations which can be used to calculate elemental dustfall rates. The solution can also be used for isotope analysis.

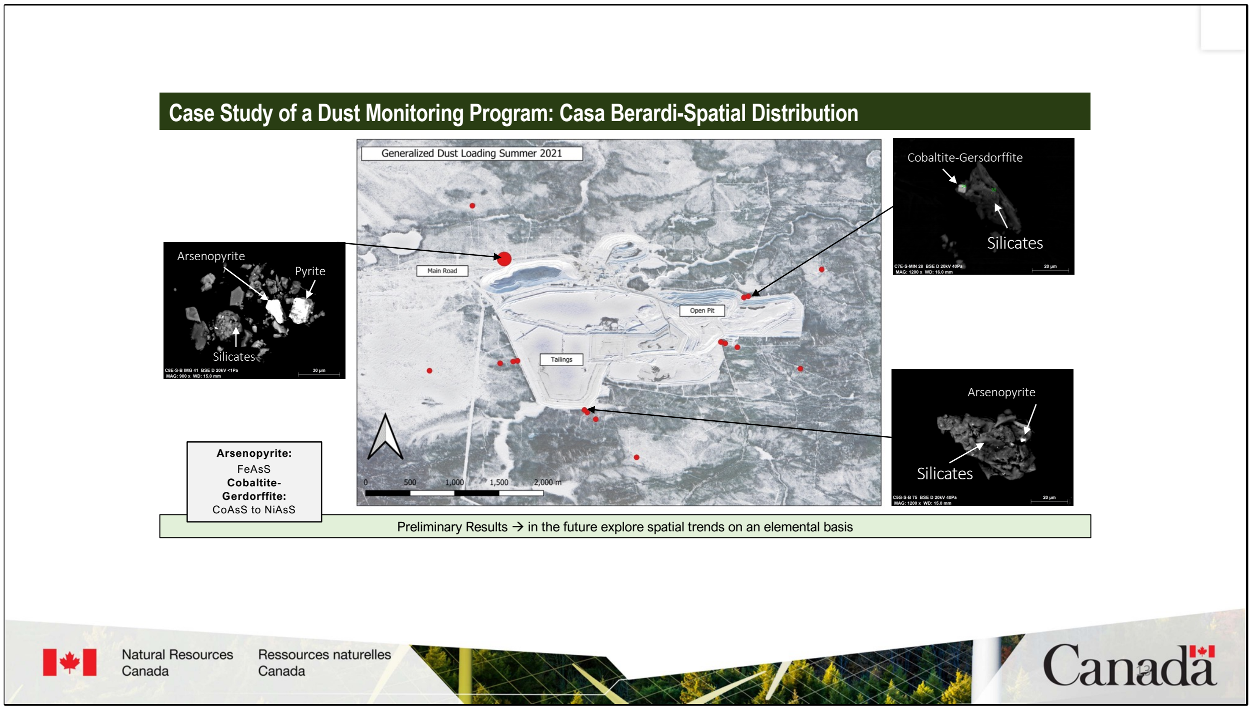
Another quarter goes towards mineralogical analysis, which I'll speak to in more detail on the following slide. Mineralogical characterization is important to support both the source appointment as well as evaluate metal mobility in the surrounding environment.

The last two quarters are for QA/QC as well as a spare- in the past we've used the spare for solubility tests.



Notes: As mentioned, the foam filters provide the opportunity to directly characterize captured dust. However, analysis of these dusts is not without challenges. The filter surfaces are not ideal for most mineralogical techniques, where particles are usually characterized in a stable, flat, and polished section. Our current work has been investigating methods to best characterize the dusts hosted by the filters, such as looking at the filter directly under a SEM (as picture in the top), using an ultrasonic bath in acetone to remove the dust particles for subsequent XRD analysis, dabbing the surface of the filters with a pin stub and carbon coating the sub-sample for subsequent TIMA analysis (automated SEM based technique), as well as investigating the use of Laser-ablation ICP-MS. Based on these techniques, we have the ability to identify the major, minor and accessory minerals and their relative abundance.

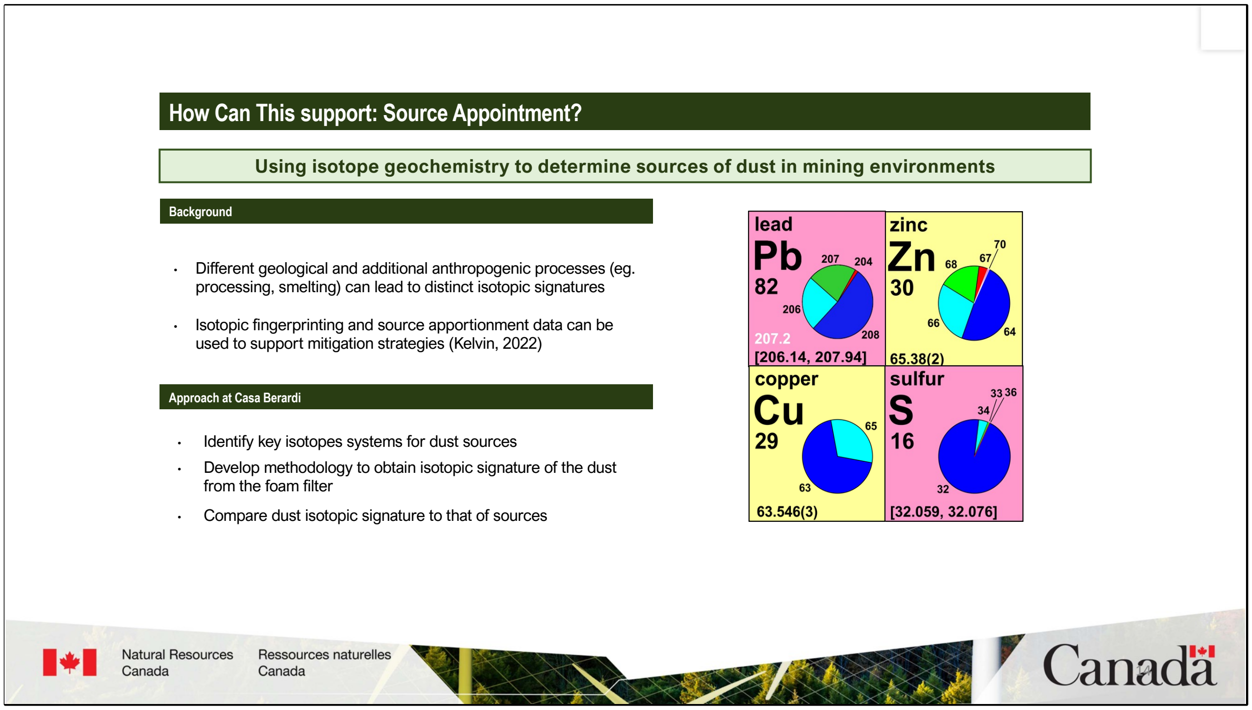
The images on the bottom show the arsenic hosting phases which have been identified. We have looked at 5 filter subsamples. Based on current results, the major mineral assemblage in the dusts are silicates, such as quartz, plagioclases, micas, and clays. And multiple sulfides have been identified amongst the accessory phases. One of these is arsenopyrite, a primary host of arsenic in the mine's geological setting. We have also identified a few occurrences of the nickel-arsenic-sulfide Gersdorffite-Cobaltite. This tells us that arsenic is hosted in multiple phases within the dust, which has implications for how arsenic in the dust may interact with the environment.



Notes: This slide demonstrates the very preliminary spatial distribution trends. In general, we have observed that the highest dust loading is beside the main road into the mine site (larger red dot in the upper left). This is seen both visually by looking at the filter and from the weights of the filters themselves.

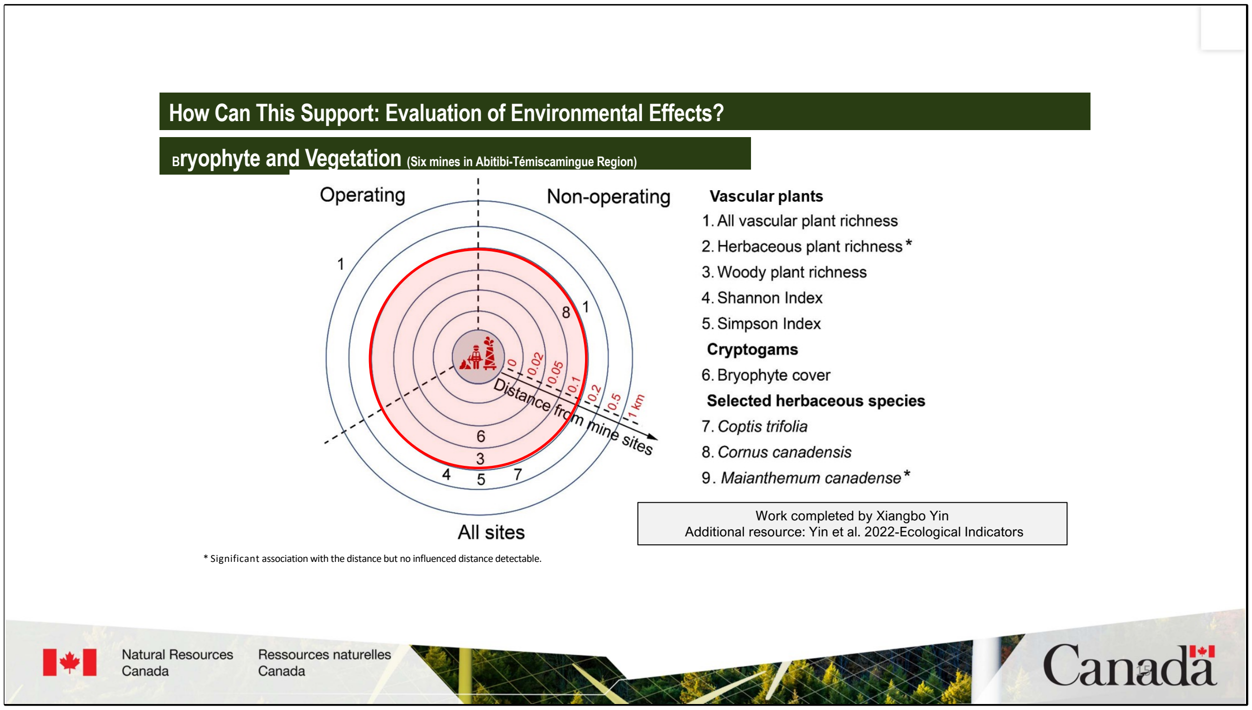
We haven't had the chance to look at the spatial trends on an elemental bias at this time. However, we hope to correlate the elemental trends with mineralogical observations.

This map shows three examples of this, where we have observed different mineralogical phases at different filter sampling locations. These are examples of the information we plan to gather to help to support our understanding of spatial trends, source appointment and the evaluation of environmental effects.



Notes: So, how can this information support source appointment? As you are likely aware, different geological and anthropogenic process can lead to distinct isotopic signature. This isotopic fingerprint data can be used to support dust mitigation strategies.

Our proposed approach at Casa Berardi is to identify key isotopes, and compare the isotopic signature to that of the sources. This is being completed with Michelle Kelvin and Matt Leybourne at Queen's University.

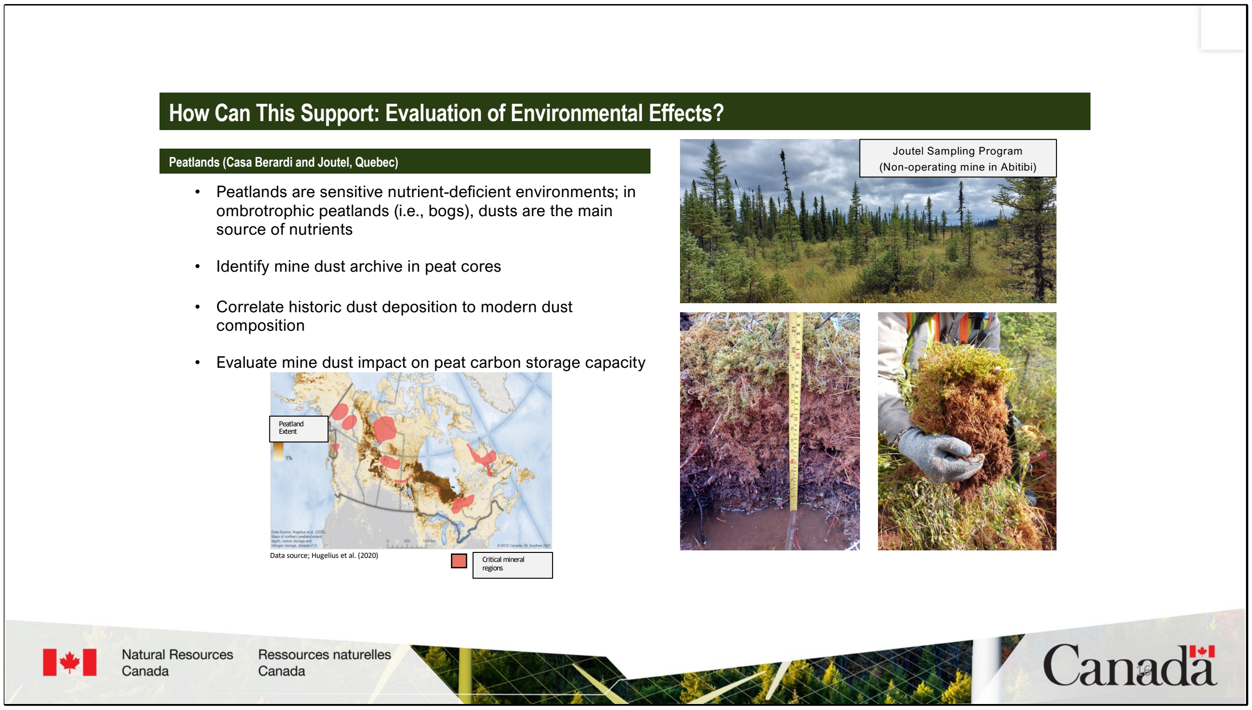


Notes: As mentioned, one of our main objectives, is looking at how dust impacts the environment. At each sampling location at Casa Berardi, our partners have taken soil and vegetation samples.

This slide illustrates work completed by Xiangbo Yin, who looked at different plants species or ecological indicators. The image shows the distance at which these different indicators were affected by either operating or non-operating mines.

While a few indicators showed an effect at greater distances the vast majority of effects were limited to 200 m from the mine for both operating and non-operating mines.

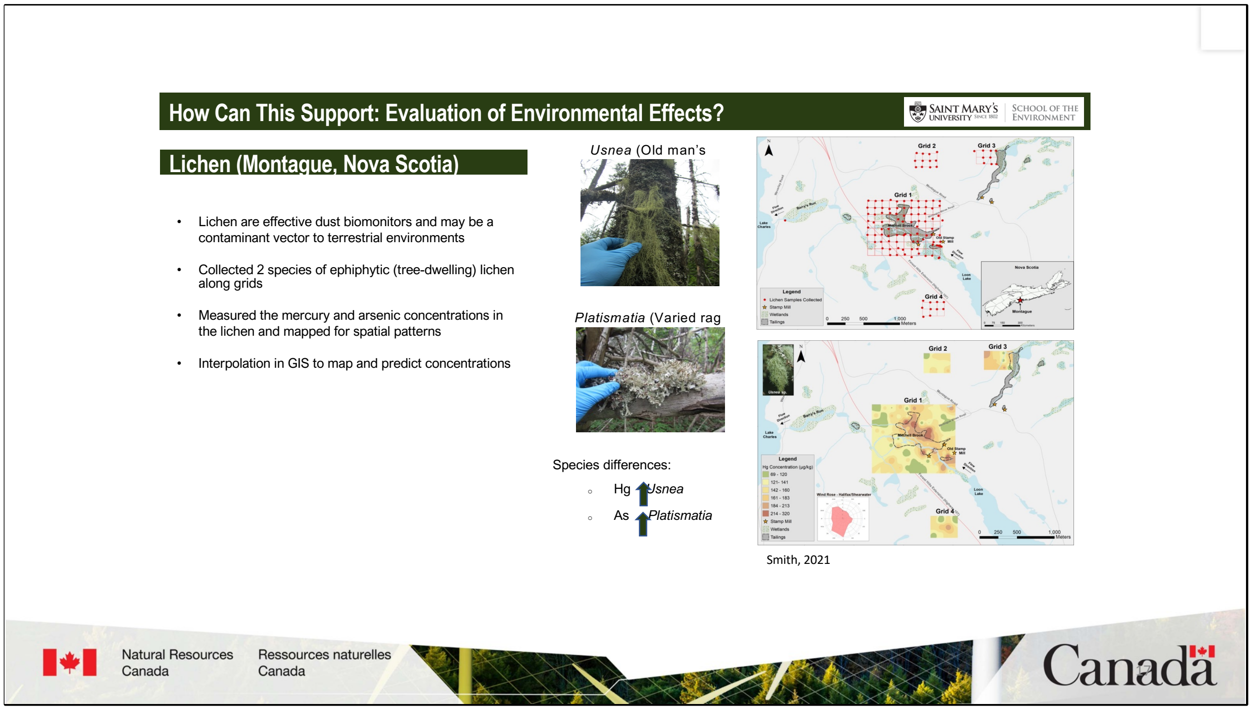
We hope to compare this to the dust deposition results.



Notes: We have also started a project to evaluation mine dust impact on peatlands, which is being lead by Eleanor Berryman at CanmetMINING.

Peatlands are the world’s largest terrestrial carbon store; and the extent of Canada’s peatlands is obvious on the map shown where the red areas represent critical-mineral regions. You can see that these regions of future development are located alongside peatlands. This raises the question of what the impact of mine dusts is on peatlands. Will fertilization lead to increase primary productivity and more carbon storage? Or does overfertilization result in peat degradation and carbon release? Work on this topic is scarce, not in Canada, and doesn't have a cohesive answer.

By looking at peat cores, we can extract an archive of mine dusts. Furthermore, we can try to correlate changes in mine dust deposition to peat productivity; to see how mine dusts affected the peat carbon storage capacity.

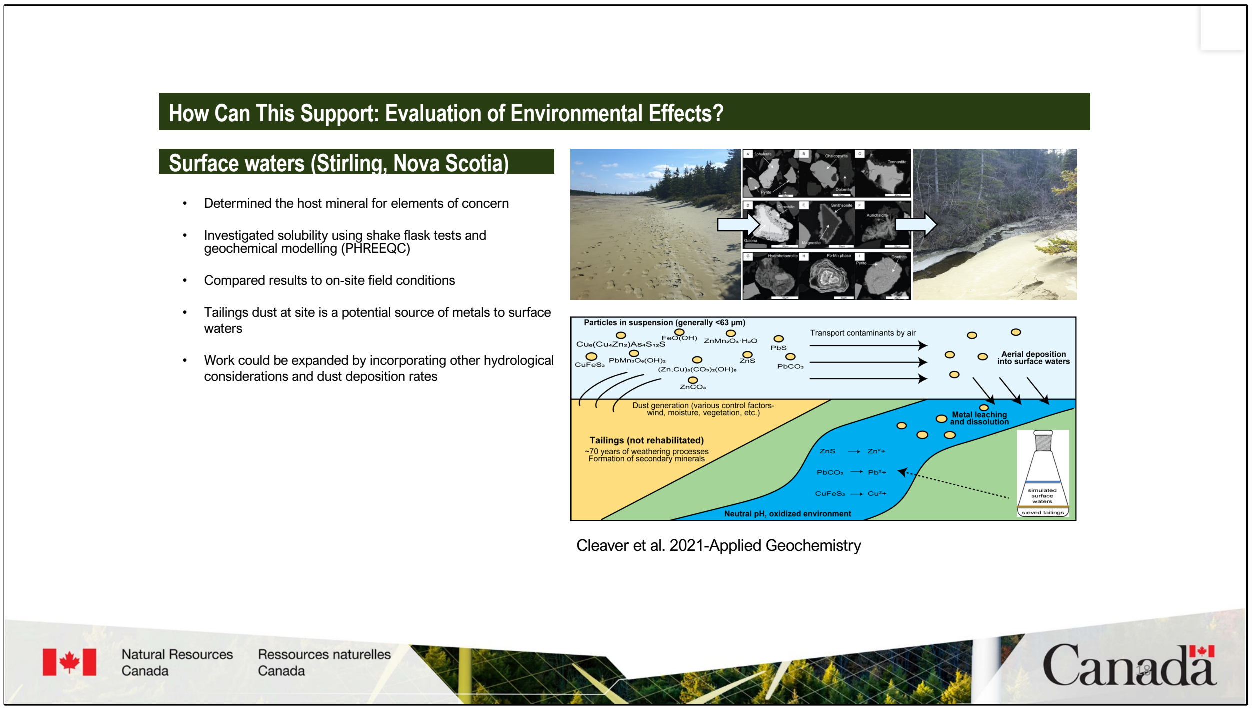


Notes: Dust can also impact lichen.

Lichen receive nutrients from the atmosphere and have 3 major accumulation pathways. Since lichens can accumulate elements in these ways, they make for effective bio monitors tools, but can also help to assess risk to ecosystems. For example, lichens can be a vector to terrestrial environment (nesting material, food source).

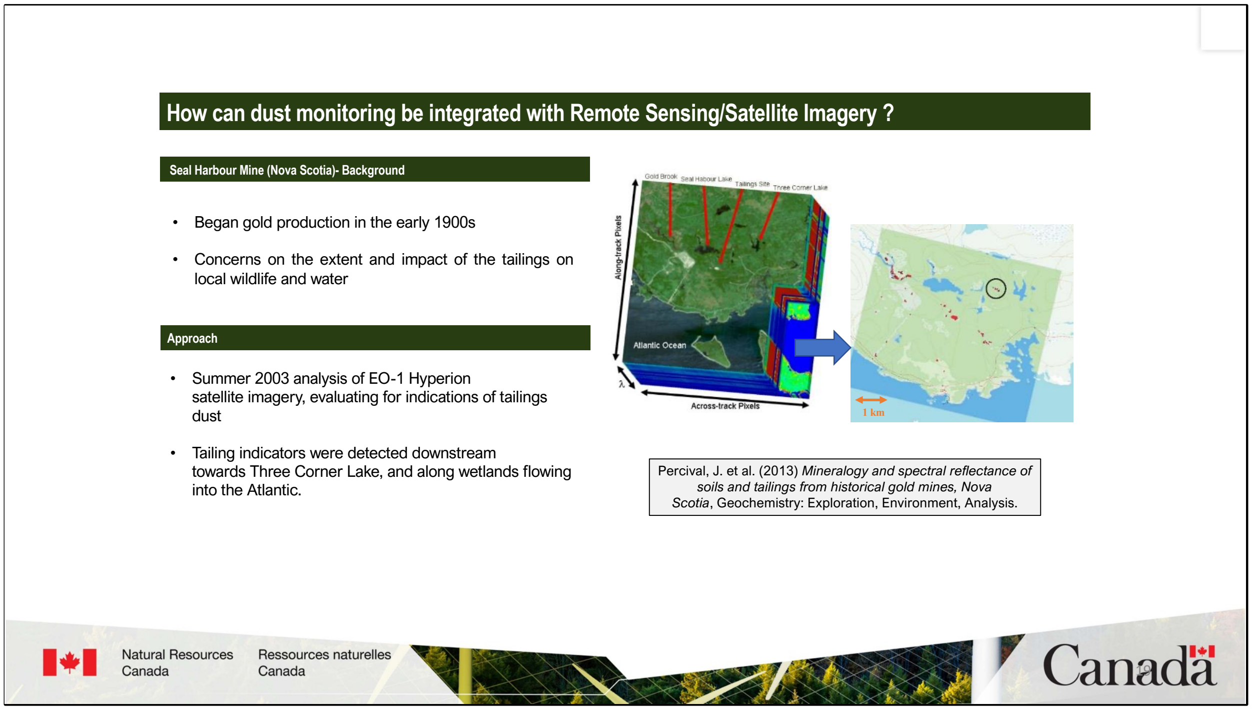
For this study, lichen sampling was conducted at the Montague gold district, which is a historic mine site located in Nova Scotia.

Sampling was completed over 4 grids with samples sites 100 m apart; as shown in the images on the right. During sampling, we collected two species of tree-dwelling lichen along the grids; Old man's beard and varied rag lichen. The goal was to measure the mercury and arsenic concentrations in the lichens and map for spatial patterns, which was done using GIS as shown here. Results were than compared to tailings and passive samplers. You can see in the map that the highest concentration were located north of the tailings, in the darker red. This work was completed by Michael Smith at Saint Mary's University with Carrie Rickwood and Linda Campbell.



Notes: This type of information can also be used to evaluate the impacts to surface waters.

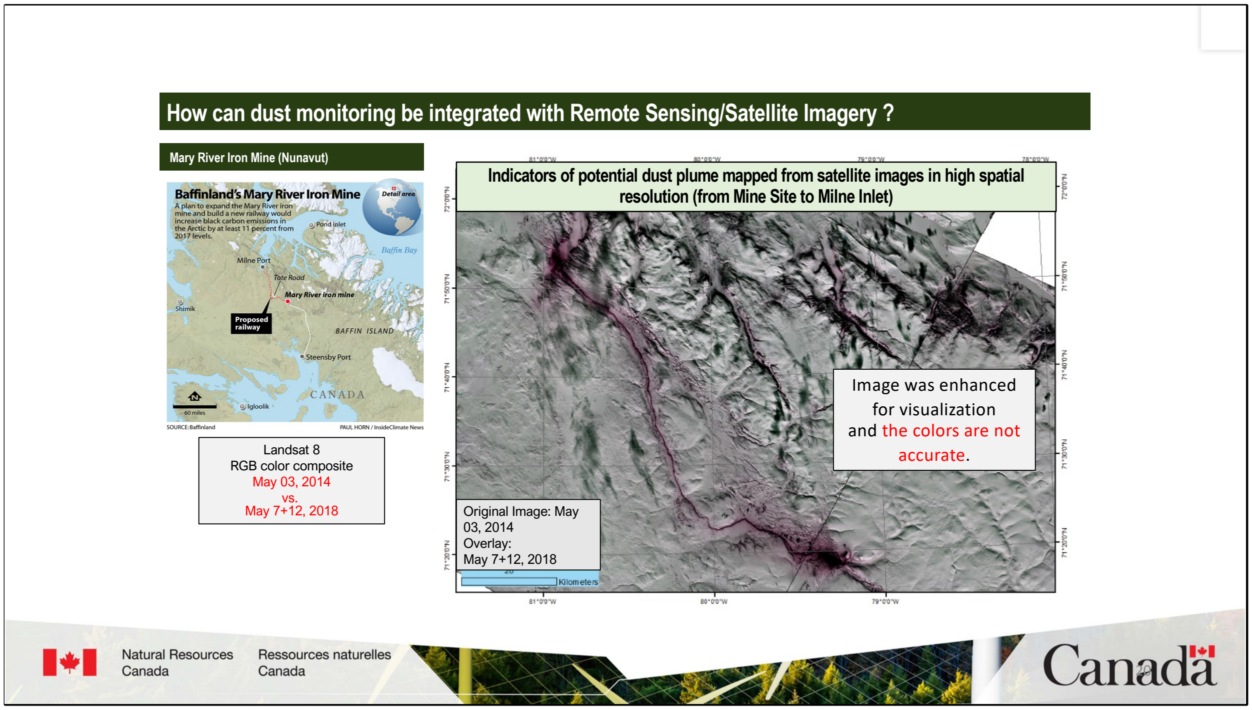
At Stirling, Nova Scotia, an abandoned Zn-Pb-Cu mine, we used sieved tailings as a proxy for dust as we had yet to explore mineralogical techniques on the filters directly. Using the sieved tailings, we determined the host mineral for the elements of concern, which included both primary sulfides and secondary phases. We then investigate the solubility of these samples in simulated stream waters using shake flask tests and PHREEQC. From the mineralogy information and solubility test, we were able to determine the main minerals likely to leach metals into surface water. We then compare these results to on-site field conditions, such as the surface water chemistry and passive sampling data and found similarities. This indicated that at this site tailings dust was a potential source of the metals to surface waters. A limitation of this work is that we didn't quantify the significance of metal leaching into surface waters from dust. Therefore, this work could be expanded by incorporating other hydrological considerations and dust deposition rates.



Notes: Another objective for our team is the incorporation of remote sensing and satellite imagery, which is led by Peter White and Liming He, at the Canadian Center of Remote Sensing. I'll now go through a few examples of their work.

Lower Seal Harbour Mine, in Nova Scotia, is an abandoned gold mine which operated in the 1990s. Using the satellite imagery analysis, they were able to detect regions where dust has been concentrated by wetlands over time, which could be tracked downstream to the Atlantic Ocean. This includes the circled area in the upper right where no one had expected to see tailings, where they expect snowmelt had transported some of the tailings.

The site had a significant effort in field work to validate these studies by ground sampling for fugitive dust.



Notes: Fugitive dust around the Mary River Mine in the Baffinland Island is a concern to the local community.

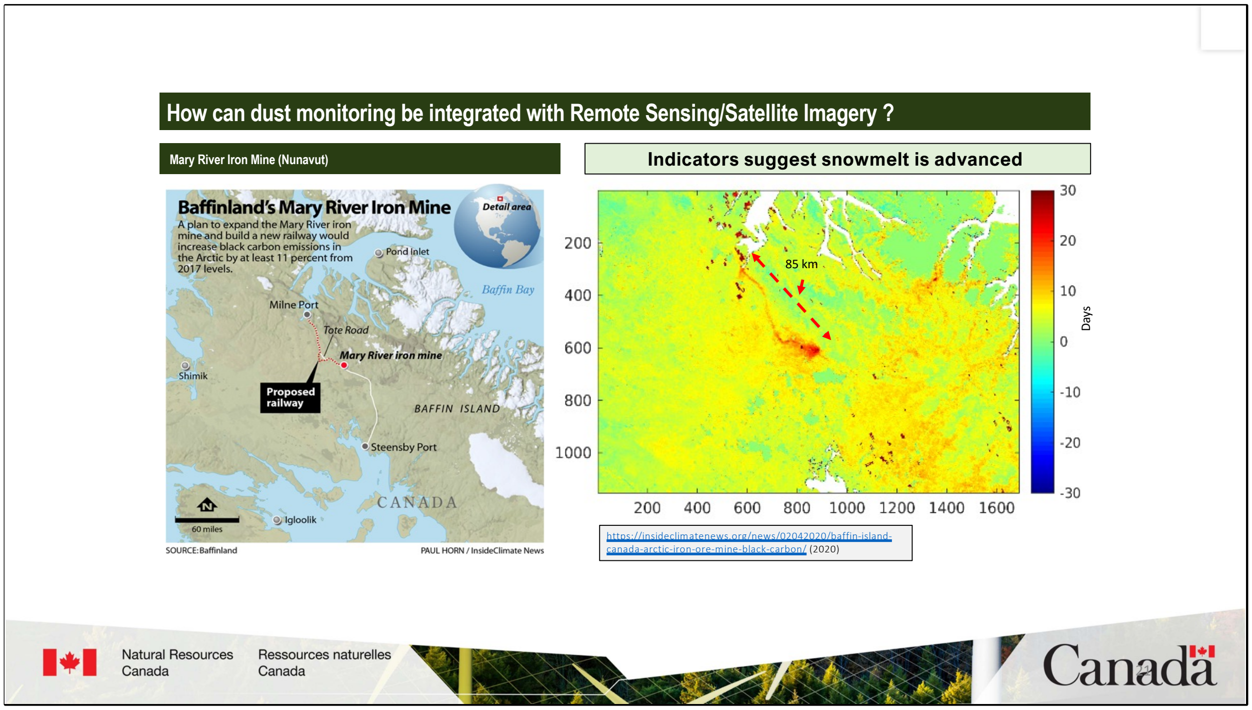
Here we used the Landsat 8 satellite images to map the extent of mine dust.

The left panel shows the location of Mary River Mine in red dot. The Mine site and the stockpile in the Milne Port is connected by a 100 km-long tote road.

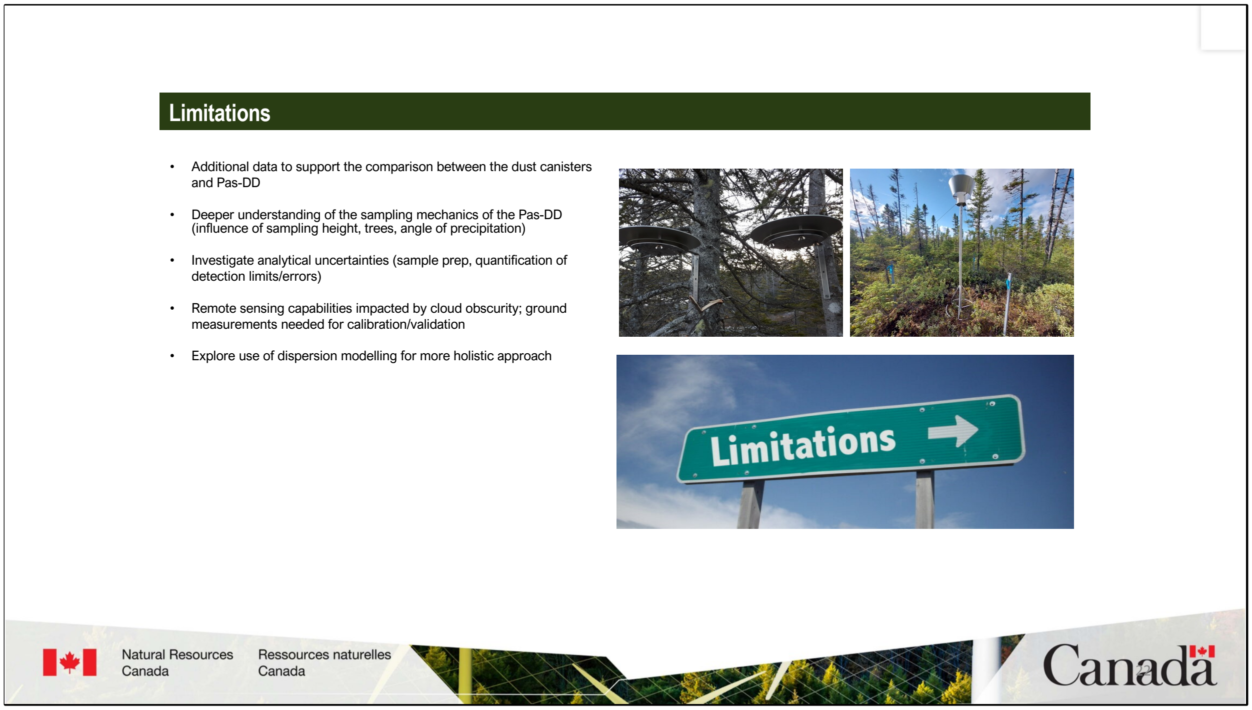
On the right side, you see that the snow color was consistent between mine site and the background, in 2014, which was before the mine's operation.

Page Down. In 2018, you can see that discolored snow around the Mine site, tote road and the stockpile is revealed; the potential dust plume, using discolored snow as an indicator, is seen 10 km away from the mine site.

Ground truthing of these results is still needed.

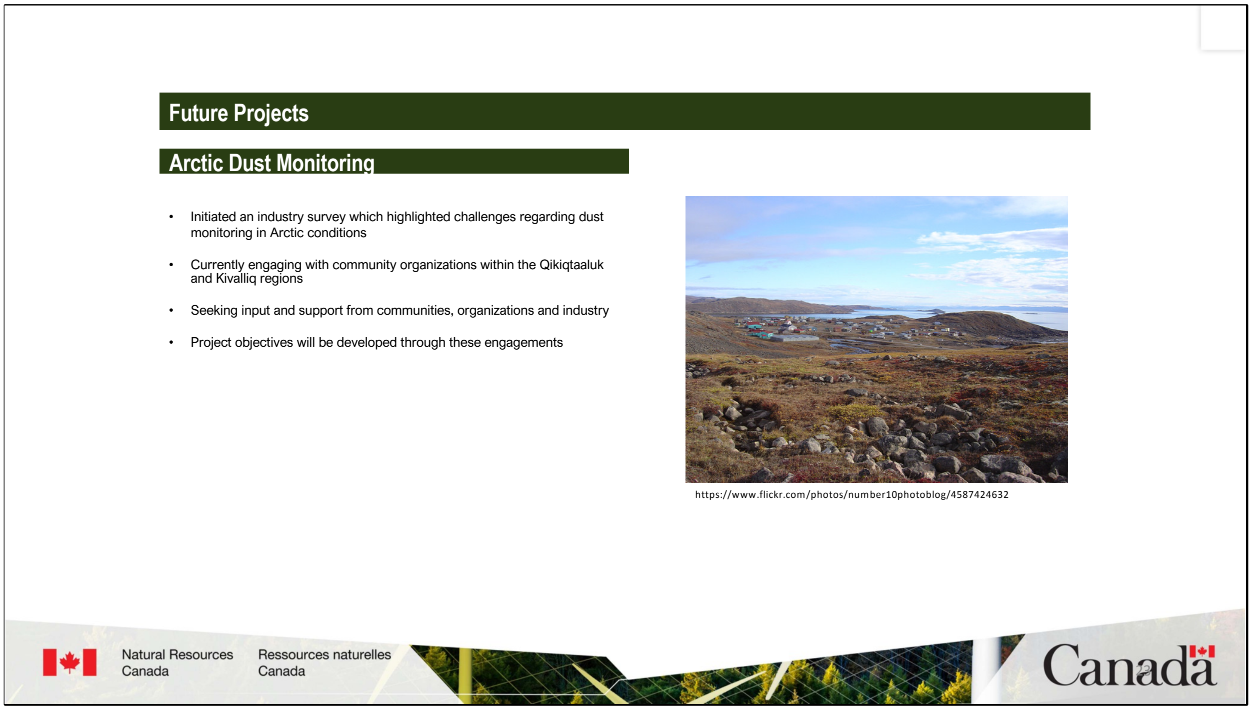


Notes: We used another satellite data set to evaluate consequence of mine dust to the local environment. Dust helps the snow to warm up and melt quicker; here we define the "first snow-free date" as the first day that accumulated snow over the winter is completely melted. As shown in the right panel, we found that the first-snow-free date around the mine's facilities is advanced by two-weeks comparing to the background area.

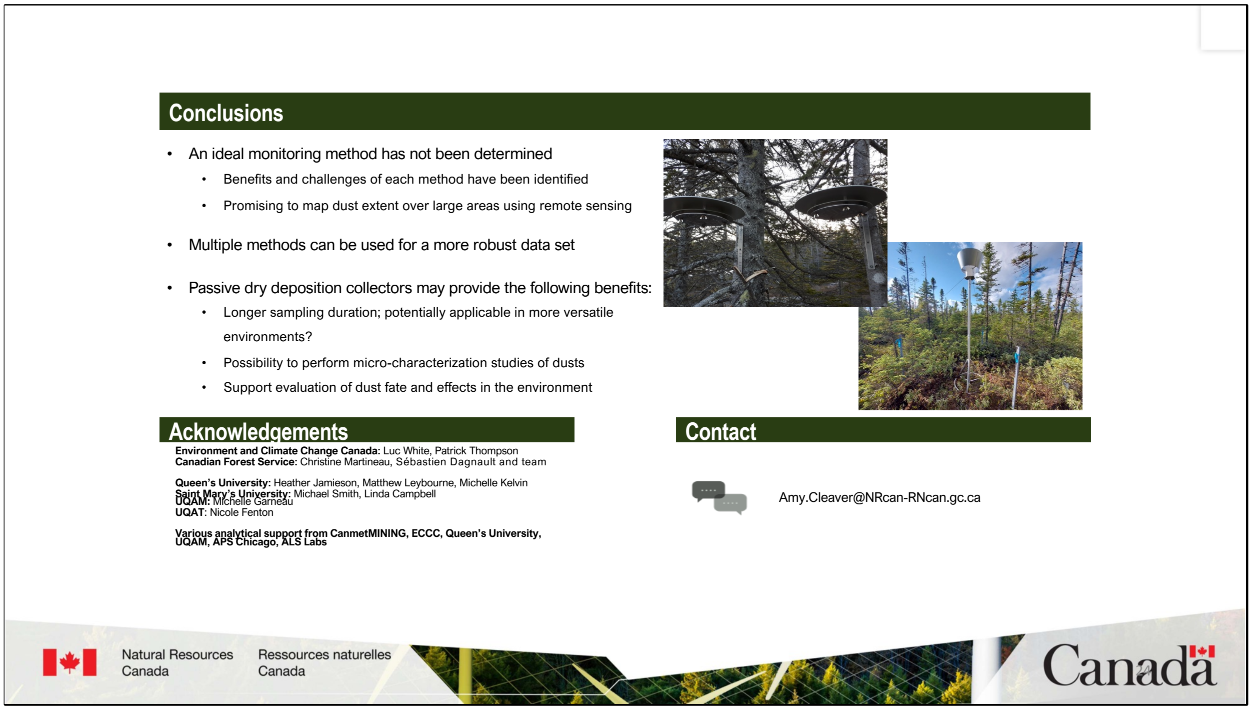


Notes: Now that I have walked through the various different application of this research. I wanted to highlight some of the limitations that we are still working though. These include:

- The need to continue the comparison between the dust canisters and the passive dry deposition collectors
- We need a deeper understanding of the mechanics of the Pas-DD- such as the influence of sampling height, trees, angle of precipitation and how these factors would influence any results
- This leads me to the next point, that we need to further investigate uncertainties, such as quantifying detection limits and errors from subsampling and sample prep
- In terms of remote sensing, further ground measurements are needed for calibration and validations
- Our team would also like to explore dispersion modelling for a more holistic analysis of our monitoring programs



Notes: In addition to addressing the limitations list, our team is currently engaging with communities and industry in the Arctic. Based on an industry survey, there are particular challenges with monitoring dust in the Arctic, including limitations of equipment in extreme cold weather and lack of access to sites on a monthly basis. Our research team would like to the test the viability of the Pas-DD under Arctic conditions and are currently engaging communities, organizations and industry for input and support, to co-develop project objectives and methodologies.



Notes: In conclusion,

- our research has not identified an ideal monitoring method without challenges, but we have been able to highlight benefits and challenges of different methods. We have also determined that using remote sensing is a promising method to map dust extent over large area.
- In particular though, the Pas-DD has various benefits including longer sampling duration and provide the possibility to preform micro-characterization studies which supports the evaluation of dust fate and effects in the environment. I've named a number of people throughout this presentation, so I'd like to acknowledge everyone involved and if you have any questions, I'm happy to take some now or feel free to contact me. Thanks for your time.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BC MEND 2022- Reference List

Fugitive Dust Monitoring and Characterization Techniques: Challenges and Opportunities

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