Fugitive Dust Risk Management Plan
2019 Annual Report

Red Dog Operations
Teck Alaska Incorporated
November 2019

Teck

Contents

Acronyms and Abbreviations

AIDEA	Alaska Industrial Development and Export Authority
CAKR	Cape Krusenstern National Monument
CSB	Concentrate Storage Building
CSP	DEC Contaminated Sites Program
DEC	Alaska Department of Environmental Conservation
DFG	Alaska Department of Fish and Game
DMTS	DeLong Mountain Transportation System
ITW	Ikayuqtit Team Technical Workgroup
MSHA	Mine Safety and Health Administration
NANA	NANA Regional Corporation
OSHA	Occupational Safety and Health Administration
PAC	Personnel Accommodations Complex
RDO	Red Dog Operations
RMP	Fugitive Dust Risk Management Plan
TDam	Main Tailings Dam
TEOM	tapered element oscillating microbalance
TSP	total suspended particulates
VEE	visible emissions evaluation
XRF	x-ray fluorescence analyzer

Summary

This document presents the Fugitive Dust Risk Management Plan (RMP) Annual Report for 2019 for Red Dog Operations (RDO), including the mine, road, and port areas.
The goal of Red Dog Operations Fugitive Dust Risk Management Program [*Minimize risk to human health and the environment surrounding the DMTS and outside the Red Dog Mine boundary over the life of the mine*] is to ensure that dust levels remain low using the elements discussed in this 2019 report. This report presents results from efforts related to each of the risk management implementation plans, including the Communication Plan, Dust Emissions Reduction Plan, Remediation Plan, Worker Dust Protection Plan, Uncertainty Reduction Plan, and Monitoring Plan. Activities are summarized below in relation to each of these plans.

The Communication Plan centers around maintaining clear communication with local communities and other interested parties about fugitive dust risk management efforts at the mine. Communication Plan activities during 2019 included regularly scheduled village visits (in 2019 specifically focused on caribou), as well as periodic meetings with NANA, the Subsistence Committee, and other stakeholders and organizations who expressed an interest in mine operations. Details are presented in the section titled “Communication Actions”, below.

The Dust Emissions Reduction Plan in 2019 included application of dust control product to the tailings beaches in the tailings impoundment using a new method of application and new product. The port road was treated with calcium chloride and regular watering during the summer months for dust suppression. The data related to a new dust suppressant that was studied for effectiveness along the DMTS road in 2018, to see if it outperforms calcium chloride as a dust suppressant while maintaining safe conditions for drivers, was evaluated in 2019. Also, data was collected from the waterless “air wash” that was previously installed at the port site in 2018, and the effectiveness study was conducted in 2019. Details are presented in the section titled “Dust Emission Reduction Actions”, below.

Activities related to the Remediation and Reclamation Plan in 2019 involved revisiting previously remediated sites to determine if restoration was progressing in accordance with Department of Environmental Conservation – Spill Prevention and Response goals. An additional site visit was

conducted with two biologists from ABR, Inc., considered restoration experts for tundra environments, to determine best practices going forward. Results of the ongoing collaborative study between Teck Red Dog, NANA, and Alaska Department of Natural Resources Plant Materials Center were documented to determine how to best revegetate the Main Waste Dump to support vegetation and to evaluate the success of various grass and forb seed mixtures. The study also evaluated the success of several locally harvested, locally adapted seed species that were previously collected in 2017 during the Noatak Native Seed Harvest. Details are presented in the section titled “Remediation Actions”, below. Additionally, the Tundra Working Group was formed with multiple stakeholders to address rehabilitation at RDO spill sites along the DMTS Port Road.

Activities related to the Worker Dust Protection Plan include ongoing programs designed to monitor and minimize workers’ exposure to dust while at Red Dog, and to facilitate comprehensive communication about these programs, policies, and practices. In 2019, worker health monitoring continued through regular blood lead level testing, results of which are reported directly to the State of Alaska by the testing laboratory, and by environmental monitoring performed by the on-site Safety & Health department. Strictly enforced policies remain in place to ensure that worker health is protected and that all work environments are safe. Teck takes employee health extremely seriously, and noncompliance with health and safety policies is not tolerated. Details are presented in the section titled “Worker Dust Protection Actions”, below.

Activities related to the Uncertainty Reduction Plan include research and studies to reduce uncertainties related to the assessment and management of risk to humans and the environment. In 2018, 20 caribou were hunted by subsistence hunters, tissues were collected, and a caribou cooking study was conducted at an independent lab. In 2019 the data were presented at community meetings, and the major finding is that caribou harvested near Red Dog Mine remain safe for human consumption, either raw or cooked including when cooked in soups.

Activities related to the Monitoring Plan are intended to provide the necessary operational and environmental monitoring data to facilitate continued reduction of fugitive metals emissions and dust emissions, verify the continued safety of caribou and other subsistence foods and water, and monitor the health of ecological environments and habitats in the vicinity of the mine, road, and port. In 2019, monitoring activities proceeded on schedule, and statistical analyses were performed on multi-year data sets to identify and evaluate any trends and patterns. In 2019, the following monitoring programs were continued:

- Visual emissions evaluations
- Source monitoring at the mine and port with real-time air samplers
- Real-time alarm system monitoring for dust at the mine
- Road surface monitoring to assess tracking of metals
- Dustfall jar monitoring at the mine, road, and port
- Soil and vegetation monitoring

Details are presented in the section titled “Monitoring Actions”, below.

Soil and sediment monitoring fulfill specific regulatory requirements under the DEC Contaminated Sites Program (CSP), pursuant to 18 AAC 75.360. These monitoring programs are discussed in the “Monitoring Programs for DEC Oversight” section below, within the “Monitoring Actions” section. In 2018, marine sediment monitoring occurred at the Port Site. Sediment concentrations for cadmium, lead, and zinc did not exceed their respective ER-L at any of the sampling stations with the exception of lead at Station NMD. Also, cadmium, lead and zinc concentrations did not exceed the ER-Ls at more than one station for more than two annual monitoring events in a row. The next sediment monitoring event is scheduled for fall 2020. The marine sediment monitoring report is included in Appendix A. Soil sampling, which is required every 3 years, is scheduled to occur again in 2020.

Results from the 2019 monitoring programs largely indicate that concentration trends are generally decreasing over the most recent four-year period. Road surface concentrations have declined over the past four years, and dustfall jars at the port, mine and along the DMTS road have also generally declined over the past four years. TEOM concentrations have decreased during the most recent four-year period at the mine area, but not at the port site. The port site will be examined in 2020 to determine what best management practices can be added to the operational requirements.

Introduction

In accordance with the Fugitive Dust Risk Management Plan (Exponent 2008), the purpose of this report is to provide a summary of risk management activities conducted at the Red Dog operation in the prior calendar year.

Background

The Red Dog Mine is approximately 50 miles inland of the Chukchi Sea, in the western end of the Brooks Range of Northern Alaska. The mine is located on land owned by NANA and operated by Teck Alaska Incorporated (Teck). Base metal mineralization occurs naturally throughout much of the western Brooks Range, and strongly elevated zinc, lead and silver concentrations have been identified in many areas (Exponent 2007). The Red Dog Mine has been in operation since 1989.

At the mine, ore containing lead sulfide and zinc sulfide is mined and milled to produce lead and zinc concentrates in a powder form. These concentrates are hauled year-round from the mine via the DMTS road to concentrate storage buildings (CSBs) at the port, where they are stored until being loaded onto ships during the summer months. The storage capacity at the port allows mine operations to continue year-round. During the shipping season, the concentrates from the storage buildings are loaded into an enclosed conveyor system and transferred to the shiploader, and then into barges. The barges have built-in and enclosed conveyors that are used to transfer the concentrates to the holds of deep-water ships. The DMTS road passes through the Cape Krusenstern National Monument (CAKR), which is managed by the National Park Service (NPS). A study conducted by NPS in 2000 found elevated levels of metals in moss near the DMTS road, declining with distance from the road (Ford and Hasselbach 2001).

Teck conducted studies to characterize the dust issue throughout the mine, road, and port areas, and subsequently conducted a human health and ecological risk assessment (Exponent 2007) to estimate possible risks to human and ecological receptors[1] posed by exposure to metals in soil, water, sediments, and plants and animals in areas surrounding the DMTS (which includes the road corridor and port), and in areas surrounding the Red Dog Mine ambient air/solid waste

[1] Plants and animals

permit boundary and port site. The human health risk assessment evaluated potential exposure to DMTS-related metals through incidental soil ingestion, water ingestion, and subsistence food consumption under three scenarios: 1) child subsistence use, 2) adult subsistence use, and 3) combined worker/subsistence use.

The human health risk assessment, which included subsistence foods evaluations, found that it is safe to continue harvesting of subsistence foods from all areas surrounding the DMTS and mine, including in unrestricted areas near the DMTS, without restrictions. Although harvesting remains off limits within the DMTS road and port, human health risks were not elevated even when data from restricted areas were included in the risk estimates.

The ecological risk assessment evaluated potential risks to ecological receptors inhabiting terrestrial, freshwater stream and pond, coastal lagoon, and marine environments from exposure to DMTS-related metals. The ecological risk assessment found that:

- In the tundra environment, changes in plant community composition (for example, decreased lichen cover) were observed near the road, port, and mine, although it was not clear to what extent those effects may have resulted from metals in fugitive dust, or from other chemical and physical effects typical of dust from gravel roads in Alaska.
- The likelihood of risk to populations of animals was considered low, with the exception of possible risks related to lead for ptarmigan living closest to the port and mine.
- No harmful effects were observed or predicted in the marine, coastal lagoon, freshwater stream, and tundra pond environments, although the potential for effects to invertebrates and plants could not be ruled out for some small, shallow ponds found close to facilities within the port site. However, no effects were observed in these port site ponds during field sampling.

Subsequent to completion of the risk assessment, Teck prepared a Risk Management Plan (RMP) designed to minimize the potential for effects to human health and the environment over the remaining mine life and beyond (Exponent 2008).

Risk Management Plan Overview

Based on the results of the risk assessment, and stakeholder input on risk management objectives, a risk management plan (RMP) was developed to combine and build upon prior and ongoing efforts by Teck Alaska Incorporated (Teck) to reduce dust emissions and minimize potential effects to human health and the environment over the life of the mine. Specifically, the overarching risk management goal is to: "*Minimize risk to human health and the environment surrounding the DMTS and outside the Red Dog Mine boundary over the life of the mine*."[2]

Although human health risks were not found to be elevated, and potential ecological risks were found to be limited, conditions may change over time, and this possibility was also considered in the design of the RMP. Future changes in conditions and in potential human and ecological exposures over the life of the operation can be addressed through implementation of risk management, dust emissions control, and monitoring activities. More specifically, the RMP established a set of seven risk management objectives (Exponent 2008), which formed the basis for preparation of six implementation plans. Each of the six implementation plans addresses one or several of the overall objectives of the RMP (Figure 1) and includes the planned scope of work to achieve the objectives.

This annual report assumes that the reader has some familiarity with the Fugitive Dust Risk Management program, and is therefore not intended to be a thorough discussion of that program, nor is it intended to provide complete background on either the risk management program or risk assessment that led to the development of the RMP. To develop a more thorough understanding of the risk management programs, interested parties are encouraged to review the human health and ecological risk assessment documents (Exponent 2007), as well as the RMP (Exponent 2008) and its component implementation plans:

- Communication Plan (Exponent 2010)
- Dust Emissions Reduction Plan (Exponent 2011a)
- Remediation Plan (Exponent 2011b)
- Worker Dust Protection Plan (Exponent 2011c)
- Monitoring Plan (Exponent 2014)
- Uncertainty Reduction Plan (Exponent 2012)

These plans are available for review at http://www.teck.com/operations/united-states/operations/red-dog/.

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[2] Note that the mine closure and reclamation plan addresses risk management within the mine solid waste permit boundary (collocated with the ambient air boundary, see Figure 3).

Data Collection and Reporting Objectives

The risk management program includes collection of large amounts of data for various implementation plans (discussed below) that are intended for either operational or regulatory purposes. Data collected for operational purposes are intended to provide Teck with information on the effectiveness of dust emissions control and reduction efforts. Data collected for regulatory purposes are intended to provide Alaska Department of Environmental Conservation (DEC) with the necessary information to verify that conditions are protective of human health and the environment.

The soil monitoring and marine sediment monitoring programs (described in the section below regarding the summary of monitoring results) are intended to satisfy a number of requirements, including the regulatory requirements under DEC Contaminated Sites Program (CSP), pursuant to 18 AAC 75.360. These two programs are intended to provide DEC with a means to continue oversight and implement enforcement actions if necessary. As such, the results of these programs are formally documented in separate reports to DEC after each monitoring event. Sediment monitoring occurs once every two years, and soil monitoring occurs once every three years. Sediment and soil sampling did not occur in 2019 but are scheduled again in 2020. These monitoring programs are discussed in the "Monitoring Programs for DEC Oversight" section below, within the "Monitoring Actions" section.

Report Organization

The annual report summarizes work that was conducted during the 2019 calendar year related to each of the implementation plans that are part of the overall RMP. The following sections document the communication, dust emissions reduction, remediation, worker dust protection, uncertainty reduction, and monitoring actions taken in 2019.

Risk Management Actions Taken in 2019

The following sections of this annual report summarize each implementation plan, the corresponding risk management objectives, and the actions taken during the 2019 calendar year toward achieving these objectives.

Communication Actions

The Communication Plan follows from Risk Management Plan Objective #6: *Improve collaboration and communication among all stakeholders to increase the level of awareness and understanding of fugitive dust issues*. In order to achieve this objective, the Communication Plan was developed with the goal: "To establish consistent methods for communication and collaboration among stakeholders regarding efforts related to dust emission issues." The plan identified multiple types of communication actions, within three categories: communication, collaboration, and education and outreach. A number of methods from these three categories have been implemented as part of the various risk management programs within the RMP.

The following actions were taken in 2019 by the Red Dog Environmental and Communication Relations Department to increase communication and participation between Red Dog operations and the communities, and to ensure that information is being communicated to all stakeholders and communities of interest in an effective manner:

- **Community Meetings.** Red Dog continued to hold annual community meetings in the surrounding communities. In 2019, the community meetings were focused on Tuttu (caribou). Topics discussed included 1) Red Dog caribou policy, 2) factors that affect caribou migration, 3) how hunters access the haul road, 4) preliminary results of caribou monitoring studies, and 5) preliminary results of the caribou cooking study. These meetings provided the opportunity for Red Dog to give the communities updated information on operations, to learn from attendees, and to discover what other questions community members have about Red Dog. The meetings were held in the following communities in 2019:
    - Buckland
    - Kiana
    - Kivalina
    - Kotzebue
    - Noatak
    - Noorvik

    - Selawik
- **Subsistence Committee Meetings.** The Red Dog/NANA Subsistence Committee is an advisory committee made up of hunters and Elders from Noatak and Kivalina. The committee shares traditional knowledge with Red Dog Mine operators and discusses possible effects of mine operations on subsistence activities. Red Dog holds quarterly meetings with the Red Dog Subsistence Committee. This provides a key opportunity to obtain input from traditional ecological knowledge holders and Elders from Kivalina and Noatak.
    - At the Q3 Meeting, a zinc concentrate spill that occurred at Mile Post 28.5 in June 2019 was discussed. The cause of the spill and the cleanup of the concentrate was detailed.
    - At the Q4 Meeting, restoration of old spill sites (including the recent Mile Post 28.5 spill site) was discussed with the Subsistence Committee following concerns from the Alaska Department of Environmental Conservation Spill Prevention and Response Program.
- **Additional Meetings.** Red Dog presented information to the Western Arctic Caribou Herd Working Group and Northwest Arctic Subsistence Regional Advisory Council. Information was presented on the following: 1) Red Dog caribou policy to minimize RDO effects on caribou migration, 2) hunter safety programs and a new caribou monitoring program at Red Dog, 3) preliminary results of caribou monitoring studies, and 4) preliminary results of the caribou cooking study.
- **Meetings with the Kivalina IRA.** Red Dog meets regularly with the Kivalina IRA Council via the Siñgaqmiut Working Group. The Working Group was formed to address environmental concerns, human health issues, traditional land use, and other topics decided on by the Kivalina representatives. To date, topics have focused on water quality testing in the community, tailings dam information sharing, human health studies and employment.

Dust Emissions Reduction Actions

The Dust Emissions Reduction Plan is intended to achieve Risk Management Plan Objective #1: *Continue reducing fugitive metals emissions and dust emissions*. In order to achieve this objective, the Dust Emissions Reduction Plan was developed with the goal: “To reduce the amount of fugitive dust released into the environment near the DMTS and Red Dog Mine to protect human health and the environment."

Road Dust Emissions Reduction Actions. During the warmer months when snow and ice are no longer present, calcium chloride is applied to the gravel roads as a dust suppressant because it retains moisture for prolonged periods. Additionally, water trucks spread water on the port and mine site roads. Using calcium chloride in conjunction with water applications holds down dust and stabilizes unpaved road surfaces.

A new dust suppression product called Envirokleen®, which has been used with success on Canadian Arctic runways and at other Arctic mining operations, was tested and studied on the DMTS port road in summer 2018 to determine its effectiveness relative to calcium chloride. The test section of the DMTS road spanned two miles; a control section was also used. The control section received calcium chloride and water, which is has been the best management practice for multiple years. Lead, zinc, and total solids deposition rates were measured using dustfall jars along both sections of the road. The data were examined in 2019, and results from the study demonstrated that Envirokleen was not as effective at reducing dust along the DMTS road. The road surface where Envirokleen was tested eventually failed, needing to be regraded in that section; calcium chloride was applied after regrading. Additional information and the results are included in Appendix A.

Tailings Beach Dust Suppression. In 2019, a new dust suppression product was used on the main dam tailings impoundment beach at Red Dog Operations. The dust suppressant product (Pine Bind) that was used in 2016, 2017 and 2018, in combination with the crop-duster aircraft was difficult to work with. The product separated during transport, leaving the pine-tar binding agent at the bottom of the totes and the inert mixing solution above. This required extra mixing prior to use, and residual product adhered to the aircraft, requiring extra cleaning of the aircraft after use. Therefore in 2019, Envirocrust 829C was trialed on the tailings beaches.

In the past few years, RDO has used a crop-duster aircraft to apply dust suppressant on the tailings beaches. In 2019, a new piece of equipment, the Terramac RT9 was trialed at Red Dog for laying down suppressant on the tailings beach. The low ground pressure of the Terramac is ideal for tailings impoundment dust management, because the equipment can travel on the unstable and wet tailings beach conditions without sinking into the tailings. This allows for travel on the tailings beaches year round, so that dust product can be applied year-round.

The Terramac trial in 2019 proved to be successful. Application of dust suppressant was completed after an approved Safe Work Plan was developed. The ability to safely access the tailings beach in above- and below-freezing temperatures was possible. When the weather was cold, the Terramac was able to create an effective ice-cap over the tailings beaches for dust suppression, so additional dust suppressant product was not needed. The crew that operates the Terramac showed the ability to respond to fall-time dust suppressant needs quickly, and on an on-call basis. The Terramac will likely be used again in 2020.

Year-Round Air Wash. The idea of a truck wash to reduce fugitive dust has been considered as a preventative measure to reduce fugitive dust at Red Dog. However, the extreme cold conditions would prevent a water-based truck wash from being used during six months of the year; and at the port site, fresh water is limited. After some study, RDO's Fugitive Dust Task Force decided to install a "waterless" air truck wash at the Port Truck Unloading Building (TUB), using high-powered blowers to remove residual dust from the trucks following truck unloading, and before exiting the TUB. The system designed for the TUB consists of six high-powered air blowers that are typically used to dry cars in automatic car washes. This air wash system was installed in 2018 and blows residual dust off the concentrate trucks back into the TUB, where huge dust collectors (baghouses) filter out the fugitive dust. A monitoring study was implemented in October 2018 to test the effectiveness of the air wash system at removing dust from concentrate trucks. The data were examined in 2019, and results suggested that when the air wash was used, there was a significant statistical difference between the residual dust left on the truck hood, and likely upper surfaces. The air wash was effective at removing dust by almost a factor of 10. The results of this study are shown in Appendix B.

Mine Area Dust Emissions Reduction Projects. In the 2018 Annual Report, there were some noted increased in lead concentrations at the mine site dustfall jars. In 2019, the mine operators looked into best management practices and tools that could be employed to reduce fugitive dust in the mine areas. In 2019, the following actions were implemented:

- An additional dedicated water truck operator was made available each shift (including day and night), allowing round-the-clock dust suppression at the mine site.

- Looked into a dust suppression product called DC Haulage, and requested a sample from the manufacturer to test for compatibility with RDO equipment.
- A new water source for the water truck, located at the bottom of the Gyro Crusher, was planned. The water truck will be filled in five minutes instead of 20 minutes, allowing more time for watering and less time in transit.

Remediation Actions

The Remediation Plan is intended to facilitate the achievement of the Risk Management Plan Objective #2: *Continue remediation or reclamation of selected areas to reduce human and ecological exposure.* To achieve this objective, the Remediation Plan was developed with the goal: "To define a consistent method for identifying and selecting affected areas and implementing remediation and/or reclamation". Specific requirements for remediation are set forth in various permits and approved documents such as the Red Dog Reclamation and Closure Plan. The following remediation actions, focused primarily on best management practices for revegetation of RDO-impacted tundra, were implemented in 2019:

- **Revegetation of the Main Waste Dump.** In 2017, Red Dog, NANA, and the Alaska Plant Materials Center (PMC) collaborated to develop and install revegetation test plots ("test plots") on the shale cover of the geomembrane pilot study area to evaluate revegetation success on the Main Waste Dump (MWD) cover. The purpose of the study was to:
    - Evaluate the success of various grass and forb seed mixtures, fertilizer, and mulch treatments
    - Evaluate the success of several locally harvested, locally adapted seed species collected from Noatak
    - Assess the potential for the MWD to support vegetation
    - Develop a revegetation strategy to apply to the entire MWD that incorporates locally harvested arctic-adapted forbs
    - Evaluate the potential for grass-only (G) and grass-with-forbs (G+F) seed mixes to establish long-term growth on the shale cover
    - Compare the performance of plots treated with commercial mulch to un-mulched plots
    - Evaluate variable fertilizer application rates

- Evaluate the success of locally-harvested forbs, by species, to grow on the shale cover; and
- Develop recommendations for effective revegetation of material stockpiles and, potentially, other disturbed areas at the mine.

The 2019 site visit highlighted some interesting findings related to attempts to reclaim the MWD, including the following:

- Previously in 2018, the results indicated successful grass and forb regrowth on the test plots that were established in 2017. In 2018, the mulched plots out-performed un-mulched plots in a subset of test plots. However, in 2019, the percent cover was estimated at approximately 100% in both the un-mulched and mulched subplots. The plots were generally dominated by grasses from the commercial seed mixes that were applied.
- When thick grass thatch develops, it may inhibit other species of plants from seeding, because the new seedlings have to compete for resources with the dense vegetative grass mat.
- Though difficult to find due to thick mats of grasses that had formed, individual *Artemisia arctica* (*A. arctica*) and *Astragalus australis* (*A. australis*) seedlings were observed throughout the test plot area in 2019.
- The commercial mulch applied in 2017 was still present, visible, and intact in 2019 and may likely still provide moisture retention value.
- The MWD cover material consists of unmineralized weathered shale obtained from the Kivalina and Key Creek formations. Cover conditions observed on the Oxide Dump cover (previously studied) indicate this material will weather and compress. Qualitative observations during the 2019 monitoring at the MWD indicate weathering has begun. The cover material particle size range has expanded to include more fines, and the material compresses more easily.
- The soil organic matter observed in 2019 (0.67%) was slightly higher than in 2017 (0.43%) but was still very low and therefore the estimated nitrogen release was very low. The increase in organic matter may be due to the root structure of the dense vegetative grass mat that has developed on the majority of the test plot area.

    - The 2019 data indicate that the average estimated nitrogen release increased nearly two-fold since 2017. The source of this increase in unknown but may include nitrogen release from the dense, uncut grasses.
    - Irrigation is not available at the MWD test plots, and precipitation provides the only water source. Without irrigation, reliance on local precipitation as the sole source of water may stress plant growth and contribute to observed areas of desiccated grasses within the test plots.
    - A few additional recommendations resulted from the 2019 monitoring effort. First, continue analysis of soil nutrient health every two years. Second, although the combination of low organic matter, measured NO_3-N, and relatively low estimated nitrogen release supports the application of additional fertilizer, it is not recommended because it would likely confer advantages to the grasses and limit forb development.
- **The Noatak Seed Harvest Project** was started in 2015. Trained community members collected desirable seeds from forbs and grasses in Noatak. The seeds collected in 2015 and 2016 were cleaned and utilized on MWD revegetation projects, described above. In 2019, additional remaining high-quality seed was planted in species-specific harvest plots on the “Kivalina Overburden” at the RDO. The “Kivalina Overburden” is an overburden stockpile of soil material, located just south of the Tailings Impoundment. The goal of this pilot study was to utilize the remaining seed to see if the plants could be grown and harvested at the Kivalina Overburden in the future.
    - As with the MWD study described above, the growing medium was very low in organic material and rainfall was the only source of water. These conditions limited the potential for successful growth of the six species that were planted.
    - The seeds were planted in June 2018. In 2019, only three of the six species planted were observed as small seedlings. Fertilizer and mulch were not used in this pilot study, but would likely improve moisture and soil organic content, possibly enabling better results.
    - After the seeds were planted, it was discovered following conversations with the Alaska Plant Materials Center that the seeds, when cleaned and stored in a cool, dry area, may germinate even five years after harvest. This was an important piece of information that will allow seeds to be stored for remediation projects if a surplus of seeds becomes available.

- **Red Dog Tundra Working Group**. On August 2, 2019, ADEC sent a letter to RDO staff requesting additional rehabilitation work related to tundra revegetation efforts at four historical spill sites along the DMTS road. Please note, the cleanup of those sites was not in question, the letter was referring only to the grass species that were growing on the historical spill sites. The grasses were dominating the four spill sites, and that was the subject of the letter.
    - Additional parties were invited to be involved and comment on work plans, including National Park Service, EPA, U.S. Army Corps of Engineers, ADNR, U.S. Coast Guard, Northern Alaska Environmental Center, Kivalina City Council, Kivalina IRA, NANA, U.S. Army Corps of Engineers, NANA/Lynden and AIDEA.
    - Shortly thereafter, plans were made to initiate the Red Dog Tundra Working Group (RDTWG), to address restoration of tundra vegetation for these five spill sites. Another goal of the RDTWG is to plan for efficient response and cleanup coordination between agencies and Red Dog for any potential future spills along the DMTS.
    - The first RDTWG meeting occurred in Fairbanks on October 4, 2019 and the second on February 7, 2020. RDO has been working with ABR Inc.—Environmental Research and Services (ABR) tundra restoration scientists (Sue Bishop and Tim Cater), and Fuse & Traverse (Alison Kelley and Peter Johnson) to address best practices for tundra revegetation these sites.
    - It was decided that the historical spill sites that will be included in the proposed study plan for restoring tundra plants. Potential study design was discussed with Subsistence Committee members and their remarks will be taken back to the Working Group. The goal of the study is to determine which methods work best for spill sites to allow the revegetated areas to seamlessly blend in with the surrounding tundra.

Worker Dust Protection Actions

The Worker Dust Protection Plan was developed in response to Risk Management Plan Objective #7: *Protect worker health*. In order to achieve this objective, the Worker Dust Protection Plan was developed with the goal: “To minimize worker exposure to fugitive dust, provide ongoing monitoring of exposure, and ensure a comprehensive communication system.”

Safety is a core value for Teck, and Teck is committed to providing leadership and resources for managing safety and health. Accordingly, the company has developed Environment, Health, Safety and Community Management Standards applicable to their operations worldwide. In addition, Teck has a comprehensive Occupational Safety and Health Program tailored specifically to Red Dog Operations to protect worker health. The program complements the corporate standards and is designed to manage all aspects of workplace safety and health, including worker dust protection. The Worker Dust Protection Plan ties in closely with the existing health and safety programs at the mine which are overseen by the Safety & Health Department and the Medical Department.

As in previous years, worksite blood lead monitoring was conducted in 2019 by the Safety & Health Department and Medical Department. Blood lead level testing is performed for all RDO employees on a regular basis and the State of Alaska receives copies of all laboratory results directly from the third-party laboratory. In 2019, blood lead monitoring results indicated exposures were below both the MSHA/OSHA standards, which is 40 mcg/dL blood. No blood lead monitoring results for any employee tested at RDO exceeded the MSHA and OSHA standards in 2019.

Similar to years past, eight males (no females) exhibited blood lead levels that were slightly greater than the more stringent Red Dog standards. The Red Dog blood lead standards and subsequent actions are as follows:

- 0-20 mcg/dL – continue testing employee every 6 months
- 20.1-25 mcg/dL – continue testing employee every 3 months and review of use and cleaning of filter mask
- 25.1-49.9 mcg/dL – continue testing employee every month and receive counseling by supervisors
- 50+ mcg/dL – remove employee from work area, monthly testing.

Five males (zero females) had blood lead levels in the 21-24 µcg/dL range. For those five cases, the supervisor discussed elevated lead levels and reviewed work habits with the affected employee, including cleaning of mask, appropriate filter changes and lead hygiene. The other three male workers continued to be tested once every six months. No workers were removed from the job due to blood lead levels in 2019.

Uncertainty Reduction Actions

The Uncertainty Reduction Plan follows from Risk Management Plan Objective #5: *Conduct research or studies to reduce uncertainties in the assessment of effects to humans and the environment*. To achieve this objective, the Uncertainty Reduction Plan was developed with the goal: "To identify and prioritize prospective research or studies to reduce uncertainties in the assessment of effects of fugitive dust to humans and the environment."

Caribou Cooking Study. Consumption of caribou muscle (meat), liver, and kidney was evaluated in the risk assessment, but bone and bone marrow were not directly evaluated. The results of the risk assessment indicated that overall human health risks were low, including potential risks associated with consumption of metals in caribou tissue (Exponent 2007). During the planning meetings for the risk management plan, some community members from Kivalina and Noatak wondered if lead could be stored in caribou bone and marrow and become available after cooking.

In 2018, a caribou cooking study was conducted to evaluate typical lead, zinc, and cadmium levels in caribou bone and marrow, and to assess potential availability of these metals from bone and marrow after cooking in soups. Results of the study indicated cooking did not substantially alter the concentrations of metals in caribou bone or marrow, and cooking caribou in broths with ingredients of varying acidity did not have any consistent effect on the metal concentrations in the soups.

Results from a risk assessment approach indicated that soups prepared with bone, including the meat and marrow, from caribou harvested in the vicinity of the mine are safe for human consumption and would not be expected to increase health risks from exposure to cadmium, lead, or zinc in local subsistence diets. This "uncertainty reduction" study is part of the risk management process for fugitive dust. A full report documenting this cooking study is attached in Appendix C.

Monitoring Actions

The Monitoring Plan (Exponent 2014) is intended to facilitate the achievement of the following Risk Management Plan objectives:

- Objective 1: Continue reducing fugitive metals emission and dust emissions (this objective is indirectly addressed through monitoring, to verify effectiveness of operational dust control measures)
- Objective 3: Verify continued safety of caribou, other representative subsistence foods, and water
- Objective 4: Monitor conditions in various ecological environments and habitats, and implement corrective measures when necessary
- Objective 6: Improve collaboration and communication among all stakeholders to increase the level of awareness and understanding of fugitive dust issues.

To achieve these objectives, the Monitoring Plan (Exponent 2014) was developed with the goal: "To monitor changes in dust emissions and deposition over time and space, using that information to: 1) assess the effectiveness of operational dust control actions, 2) evaluate the effects of the dust emissions on the environment and on human and ecological exposure, and 3) trigger additional actions where necessary."

Actions included in the Monitoring Plan were developed from priority actions identified during development of the Risk Management Plan, with input from local stakeholders, technical experts, and State and Federal regulatory agencies. This section presents the results of the Monitoring Plan actions implemented during 2019. An overview of the components of the monitoring program with frequencies of monitoring is shown in Figure 2. A map-based illustration of monitoring program components and monitoring stations and sites is shown in Figure 3.

Monitoring Programs for DEC Oversight

The marine sediment and soil monitoring programs are subject to DEC oversight, and results are also used for trend analysis at RDO. Sediment monitoring was conducted in 2018 and is planned again for 2020. Soil monitoring was conducted in 2017 and the next soil monitoring event is scheduled for summer 2020.

Operational Monitoring

U.S. EPA Method 22 – Visible Emissions Evaluation

Visible Emissions Evaluations (VEE) were conducted as required for the Red Dog Title V air permit. Monitoring occurs at multiple locations within the mine boundary and at the port. Along all unpaved roads, including the DMTS road, calcium chloride and/or water is used to control fugitive dust emissions when the road surfaces are not frozen or when the road surfaces do not exhibit visible surface moisture. To verify these control measures are effective, VEE observations are conducted daily when road surfaces are dry and not frozen. If dust is visibly present for greater than two minutes on the unpaved road surfaces, additional calcium chloride or water is applied as soon as practicable and VEE monitoring is repeated to verify fugitive emissions are no longer present.

VEE monitoring locations are shown on Figure 3, though the locations depicted are not all-inclusive, as the locations may vary. All VEE readings that are required under Red Dog's Title V permit are submitted twice a year to ADEC as part of the permit's Facility Operating Report.

TEOM Source Monitoring

Tapered element oscillating microbalance (TEOM) samplers are used for air quality monitoring at four locations near sources within the mine and port (Figure 3). Mine TEOMs are located downwind of the pit and crusher at the Personnel Accommodations Complex (PAC), and at the main tailings dam (TDam) downwind of the tailings beach, mill, and other facilities (Figure 4). Port TEOMs are located downwind of the Concentrate Storage Buildings (CSBs) and in the lagoon area downwind of the concentrate conveyor (Figure 5).

The TEOMs produce real-time measurements of dust in air, and collect discrete samples which are then analyzed to provide airborne metals concentrations. Measurements are reported as Total Suspended Particulates (TSP), and zinc and lead concentrations are reported as TSP-Zn and TSP-Pb, respectively. TEOMs are operated continuously[3] to measure real-time TSP.

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[3] Occasional system upsets do occur as a result of weather or equipment failure. TEOM readings are monitored frequently so that system upsets are noted and corrected as soon as possible. Missing or unusable data are noted in the raw data files, and are not used in statistical trend evaluations.

Filters are used to collect TSP over 24-hour periods every third day at the mine and every sixth day at the port, then analyzed for TSP-Zn and TSP-Pb.

Statistical Trend Analysis for TEOM Data. Statistical testing methods were used to evaluate whether TEOM datasets have statistically significant temporal trends in metals concentrations. The Seasonal Mann-Kendall (SMK) trend test is a nonparametric method to investigate temporal trends in time series containing substantial seasonal variability. In this case, TEOM data were summarized on a monthly basis. Seasonal trend tests were conducted using monthly means and monthly upper limits 95th percentile concentrations to evaluate both average conditions and a measure of the upper limit. Results of the statistical trend tests for TEOM data (lead and zinc concentrations) in four locations (Mine PAC, Mine TDam, Port CSB, and Port Lagoon) are summarized in Table 1.

The calculated monthly averages for TSP-Pb and TSP-Zn concentrations are shown on Figures 6 and 7, respectively, for all four mine and port TEOM locations. The concentrations of lead and zinc in the mine area are typically higher than those in the port area (Figures 6 and 7).

- **Mine PAC TEOM Results.** At the mine, lead and zinc concentrations were typically lowest in summer months (the months with higher humidity and more road watering for dust control), and highest in winter months (the coldest, driest, and lowest humidity months, when road watering is not possible because of freezing conditions). At the Mine PAC location there was a significant decrease in lead and zinc concentrations over the most recent four-year period (2016-2019; Figures 6 and 7).
- **Mine T-Dam TEOM Results.** There was a significant increase in lead and zinc concentrations over the past four years in both mean and upper limits 95th percentile concentrations (Figures 6 and 7).
- **Port CSB TEOM Results.** At the port, measured lead and zinc TEOM concentrations are highest from June through November, corresponding with the peak shipping season. Lead and zinc concentrations detected in the Port CSB TEOM show significant increasing trends over the past four years (2016-2019), both for mean and upper limits 95th percentile concentrations (Figures 6 and 7).
- **Port Lagoon TEOM Results.** The Port Lagoon TEOM results show significant increasing trends in mean concentrations for zinc and lead (Figures 6 and 7). The upper limits 95th percentile for the Port Lagoon TEOM shows significant decreases

over the past four years (Figures 6). The Port CSB and Port Lagoon results were also analyzed as a combined data set. This combined analysis is supported by the proximity of the two port locations and the similarities in monthly average concentrations for both lead and zinc. The combined Port CSB and Port Lagoon data reflect the same scenario as noted at the Port Lagoon TEOM.

TEOM Real Time Alarm System Monitoring

Real-time TEOM data is used internally to monitor for high dust events so that mine activities can be modified (where possible) to reduce dust levels. When air quality measurements exceeded a warning level or an alarm level, the alarm status was displayed on the Red Dog weather intranet web page to notify personnel within the Mine Operations and Environmental departments to take corrective action. Examples of these corrective actions include applying water on the roads or stockpiles, or shutting down loading operations during windy conditions.

Road Surface Monitoring

Loose fine materials subject to airborne transport into the surrounding environment are sampled from the road surface at eight locations every two months. From the mine site to the port, the eight road surface monitoring station locations are:

- Mine CSB (near exit from truck loading portion of CSB)
- The Y (near the back dam, between the CSB and the Airport)
- Airport
- MS-13 (former material site where road crosses the mine air boundary)
- MS-9 (material site between the mine and CAKR)
- R-Boundary (northern boundary of CAKR)
- MS-2 (material site just inside the northern boundary of the port)
- Port CSB Track (road near exit from truck unloading building at the port CSBs)

Samples were analyzed using a portable XRF (x-ray fluorescence) analyzer to determine lead, zinc, and cadmium concentrations within road surface materials[4].

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[4] The road dust samples are prepared at the Environmental Department Clean Room. The samples collected in August and October 2019 from the Mine CSB and MS-13 areas were inadvertently switched due to human error. The Figures were corrected after realizing the error by examining the prepared sample cups and the leftover material that was collected from the road. Also, in 2019, cadmium concentrations were not provided, leaving the 2019 cadmium data blank in the associated Figures. In

During the most recent four-year period (2016-2019), statistical analysis indicates that road surface concentrations have decreased for lead and zinc concentrations at stations located along the DMTS road and at the port site (Figures 8 and 9 respectively; Table 2). Lead and zinc concentrations were stable at the mine monitoring stations during the same time period (Figures 8 and 9; Table 2). Cadmium concentrations decreased at the mine and port stations in the past four years, and remained stable along the road stations (Figure 10 and Table 2).

Note that if measured road surface concentrations at stations outside the mine ambient air boundary exceed Arctic Zone Industrial Cleanup Levels for lead, zinc, or cadmium (800, 41,100 and 110 mg/kg respectively[5]) for more than two consecutive sampling periods, that road section is to be remediated and resurfaced as described in the Remediation Plan (Exponent 2011). No additional road remediation was required during 2019 because results for stations outside the mine and port boundaries did not exceed Arctic Zone Industrial Cleanup Levels for lead, zinc, or cadmium in 2019.

Dustfall Jar Monitoring

Dustfall jars are passive continuous collectors used for measuring dust deposition. Samples are collected every two months at all locations. Approximately 86 dustfall stations are located around the mine, port, and DMTS road, as follows:

- At the mine, approximately 34 jars are placed in locations around the facilities (Figure 3).
- Along the DMTS road, 12 dustfall jars are located at three stations, each with four dustfall jars, two on either side of the road. The DMTS road stations are collocated with road surface sampling stations near the port boundary, the CAKR northern boundary, and midway between CAKR and the mine. The dustfall jars are located approximately 100 m from the shoulder of the DMTS, with 100 m between them, oriented parallel to the road (Figure 3).

2020, we will be switching the protocol and sending the samples to an outside lab to minimize human error.

[5] Cleanup levels according to 18 AAC 75.341, as revised in 2008 (available on the internet at https://dec.alaska.gov/spar/csp/docs/75mas_art3.pdf). Note that the cadmium and zinc cleanup level would be lower, at 79 and 30,400 mg/kg, if the zone were considered to be the “Under 40-inch Zone” by DEC, which is a function of the definitions at 18 AAC 75.990.

- At the port, 38 jars are placed roughly in a rectangular grid throughout the area (Figure 3).
- An additional two jars are considered reference stations, one upwind of the road near Evaingiknuk Creek, and another near the Wulik River, to the north of the operation (Figure 3).

Statistical Trend Analysis for Dustfall Jar Data. Temporal trends in deposition rates or metals concentrations in dustfall jar data were evaluated using seasonal trend tests conducted with bi-monthly mean and 95th percentiles (method same as discussed above in TEOM section).

- **Lead.** For lead, dustfall deposition rates have been relatively stable over the most recent four-year period. No statistically-significant trends were identified in lead deposition rate during the most recent four-year monitoring period at the mine, along the DMTS road, or port (Table 3). Also, no statistically significant trends were detected along the DMTS road. However, a statistically significant increase in lead concentrations at the mine dustfall jars was detected for both average and upper limits, and also at the port for the upper limits only. Time series plots of lead concentrations and dustfall deposition rates are presented in Figures 11 and 12, respectively.
- **Zinc.** Zinc concentrations and dustfall deposition rates have been stable over the most recent four-year period. No statistically-significant trends were identified at any location over the most recent four-year period, either in average or upper limits (Table 3, Figures 13 and 14). At the mine, there were significantly decreasing trends in zinc dustfall deposition rates for upper the upper limits over the last four years (Table 3, Figure 14).
- **Total Solids.** For total solids, the deposition rates have been stable with no statistically-significant trends identified at any location over the most recent four-year period, either in average or upper limits (Table 3). Time series plots of total solids dustfall rates are presented in Figure 15.

Caribou Tissue Monitoring

Red Dog Mine is located within the normal annual range of the Western Arctic Herd. Surveys of caribou have been conducted periodically since 1984 by the Alaska Department of Fish and Game (ADFG), and have provided baseline information against which more current studies may be compared. Previous caribou tissue monitoring events near Red Dog were completed in

2002 and 2009 and 2018. The next caribou tissue (meat, kidney, liver) monitoring event is currently scheduled for 2025.

Summary of Monitoring Results

The goal of Red Dog Operations Fugitive Dust Risk Management Program [*Minimize risk to human health and the environment surrounding the DMTS and outside the Red Dog Mine boundary over the life of the mine*] is to ensure that dust levels remain low using the elements discussed in this 2019 report. Results from the monitoring programs largely indicate that concentration trends are generally decreasing over the most recent four-year period. Table 4 provides an at-a-glance overview of the results of dust monitoring programs.

Road surface and dustfall jars generally indicated significant decreases in lead and zinc concentrations over the past four-year period (2016-2019). The Mine PAC TEOM results also suggest significant declines over the past four-year period. Dustfall jars located all around the mine area show significant decreases in lead and zinc deposition rates (although lead and zinc concentrations have increased). The TEOMs at the port and mine mostly indicate statistically significant increases in lead and zinc concentrations between 2016 and 2019.

Overall, RDO has made improvements at controlling dust along the road and at the mine areas, but additional insights are needed at the port area; the port area best management practices will be explored further in 2020. Data from 2020 will also reveal if additional actions taken at the mine area (discussed above in Dust Emissions Reduction Actions) have been effective. Overall, environmental media concentrations remain similar to those evaluated in the DMTS risk assessment (Exponent 2007).

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Exponent, 2011c. Fugitive Dust Risk Management Worker Dust Protection Plan. Prepared for Teck Alaska Incorporated. October 2011.

Exponent, 2012. Fugitive Dust Risk Management Uncertainty Reduction Plan. Prepared for Teck Alaska Incorporated. October 2012.

Exponent, 2014. Fugitive Dust Risk Management Monitoring Plan. Prepared for Teck Alaska Incorporated. May 2014.

Ford, S., and L. Hasselbach, 2001. Heavy metals in mosses and soils on six transects along the Red Dog Mine haul road, Alaska. NPS/AR/NRTR-2001/38. National Park Service, Western Arctic National Parklands.

Teck. 2016. Reclamation and Closure Plan, Red Dog Mine, Alaska, USA. August 2016.

Fugitive Dust Risk Management Plan

RISK MANAGEMENT OBJECTIVES	Communication Plan	Dust Emission Reduction Plan	Remediation/ Reclamation Plan	Monitoring Plan	Uncertainty Reduction Plan	Worker Dust Protection Plan
1. Continue reducing fugitive metals emissions and dust emissions	□	■	□	■	□	
2. Conduct remediation or reclamation in selected areas	□		■	□	□	
3. Verify continued safety of caribou, other representative subsistence foods, and water	□			■	□	
4. Monitor conditions in various ecological environments and habitats, and implement corrective measures when action levels are triggered	□			■	□	
5. Conduct research or studies to reduce uncertainties in the assessment of effects to humans and the environment	□			□	■	□
6. Improve communication and collaboration among all stakeholders	■	□	□	□	□	□
7. Protect worker health	□	□	□	□	□	■

■ Implementation plan directly addresses objective

□ Implementation plan indirectly addresses objective

Figure 1. Risk management objectives and associated implementation plans

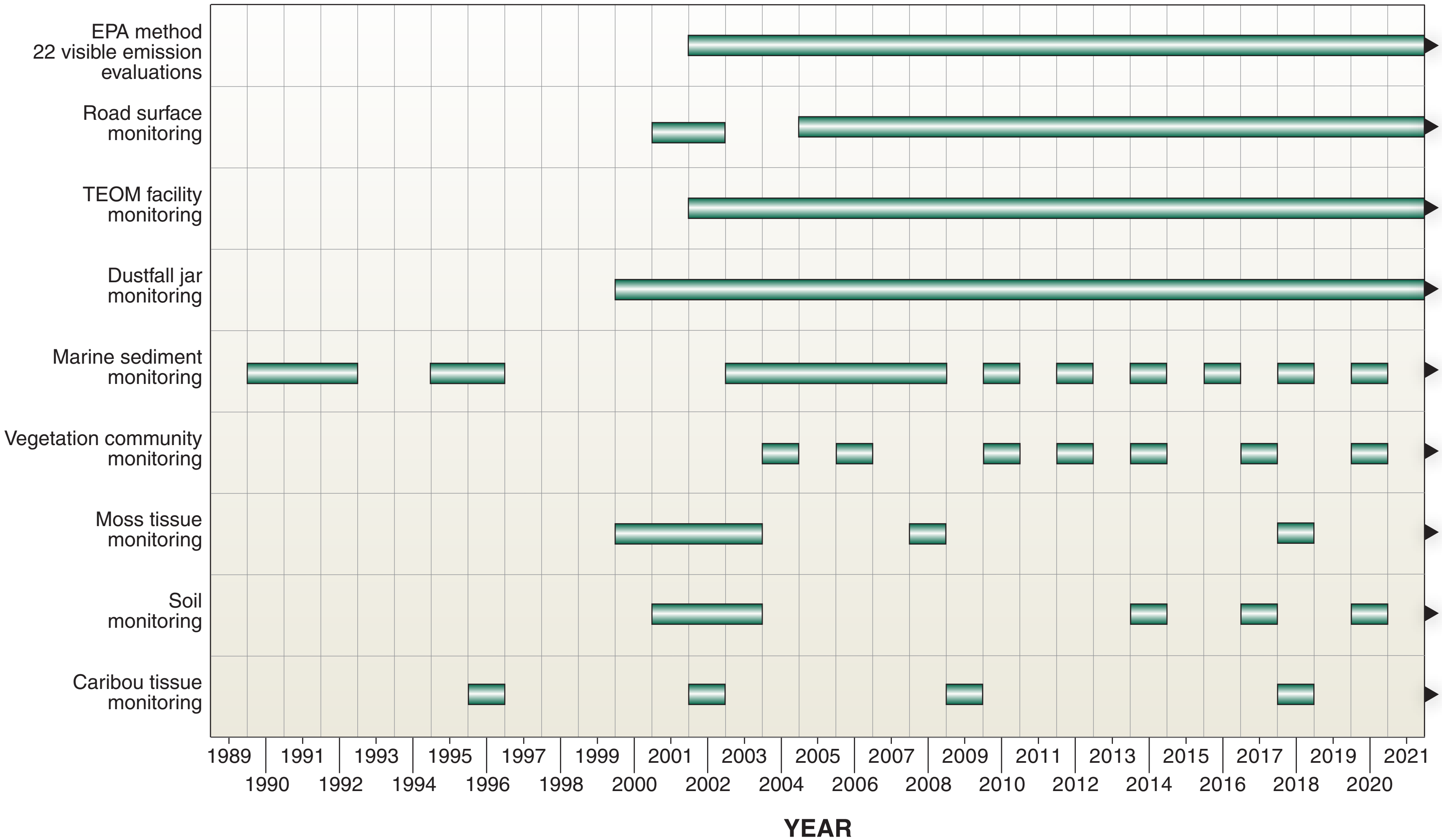


Figure 2. Monitoring timeline with program frequencies

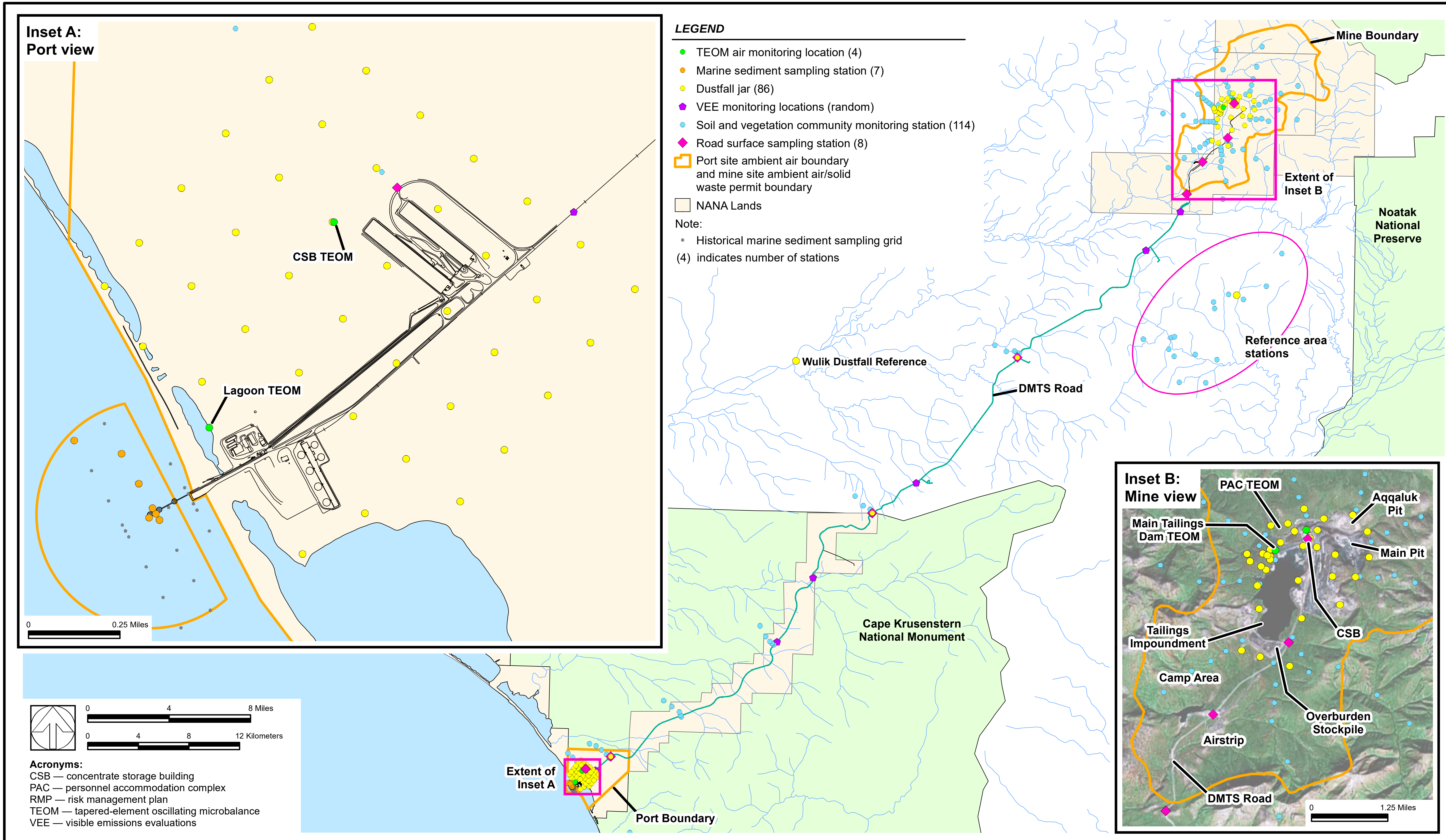


Figure 3. Overview of risk management monitoring programs

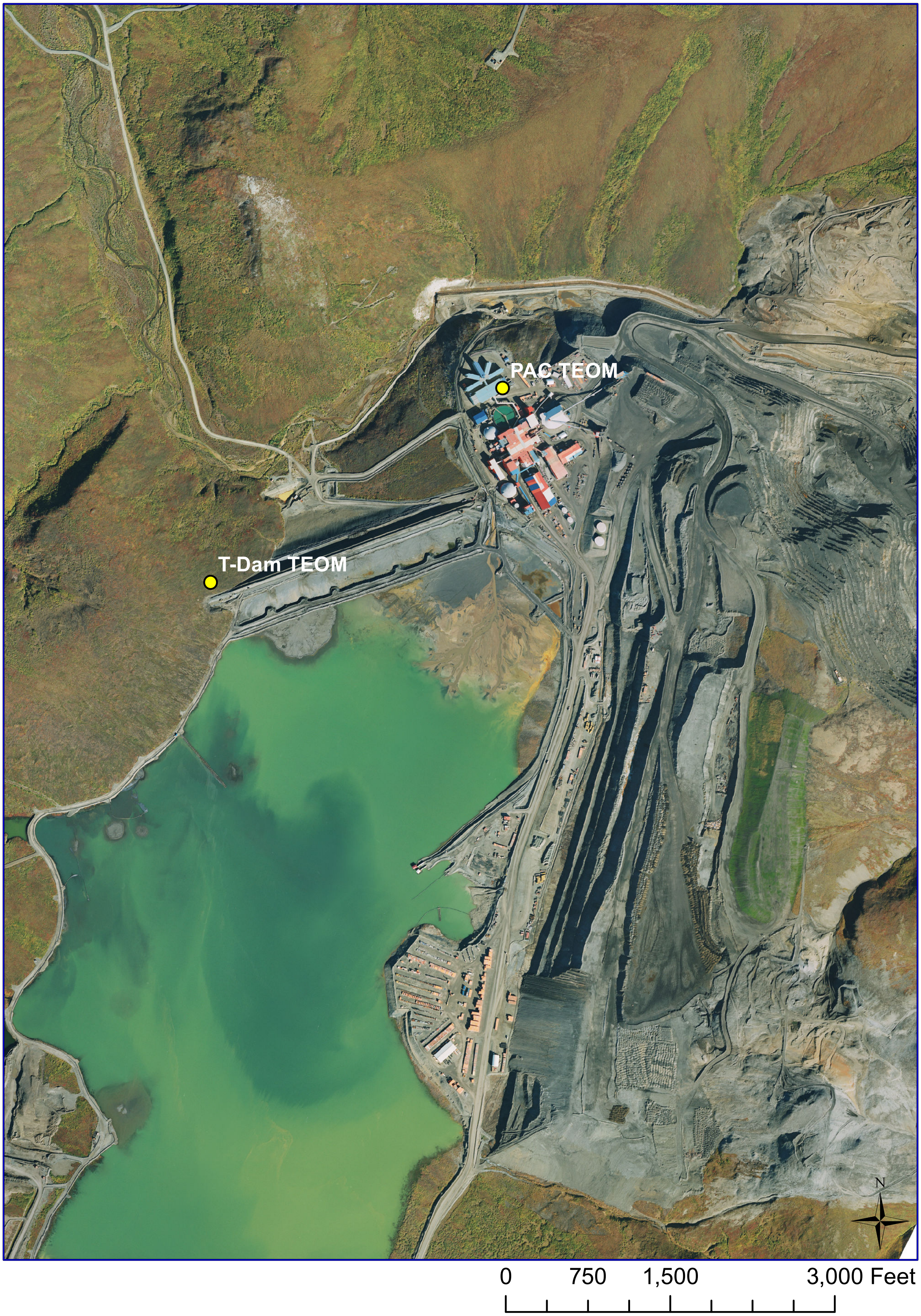


Figure 4. Mine TEOM locations

Figure 5. Port TEOM locations

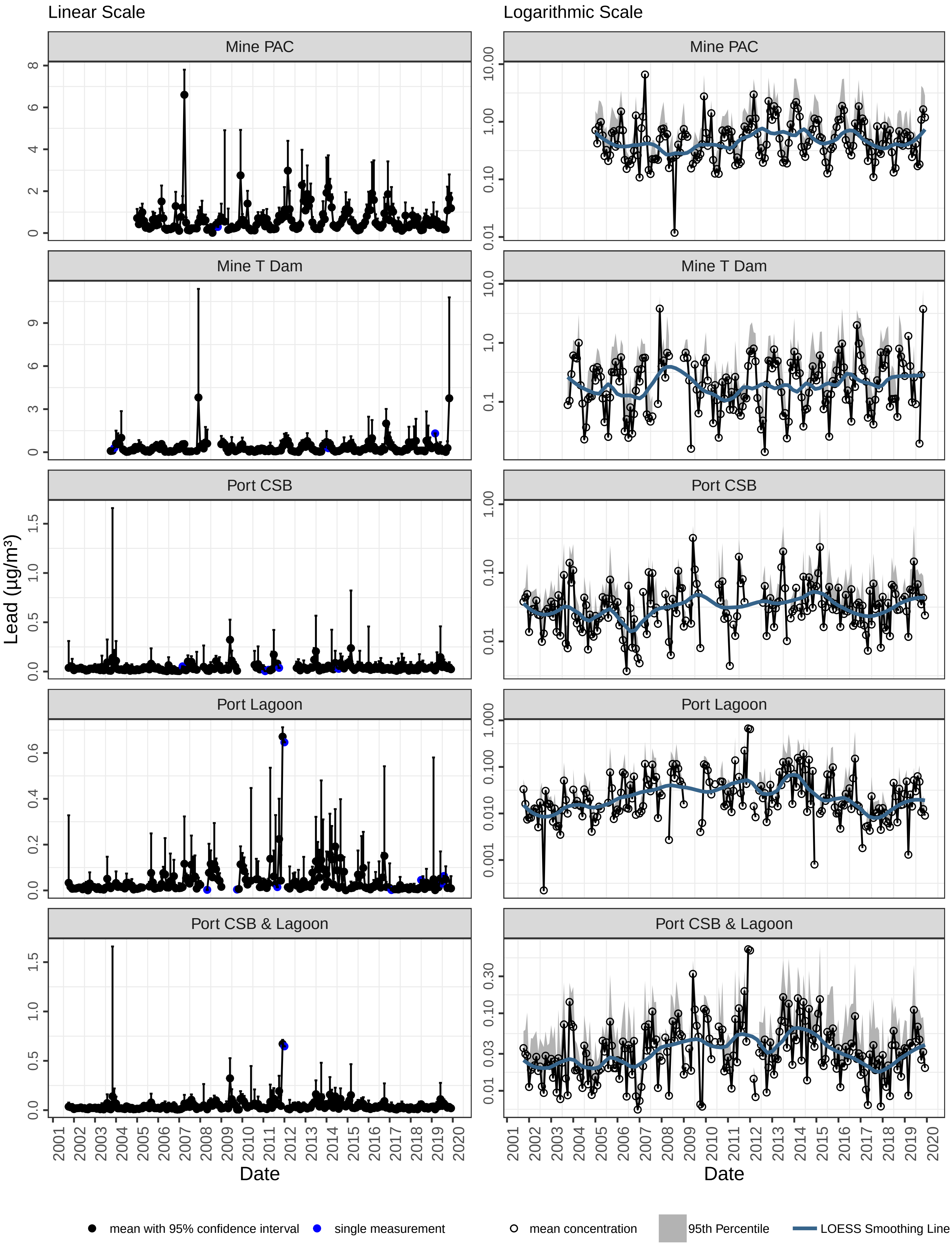


Figure 6. TEOM Lead Concentration plots (all years)

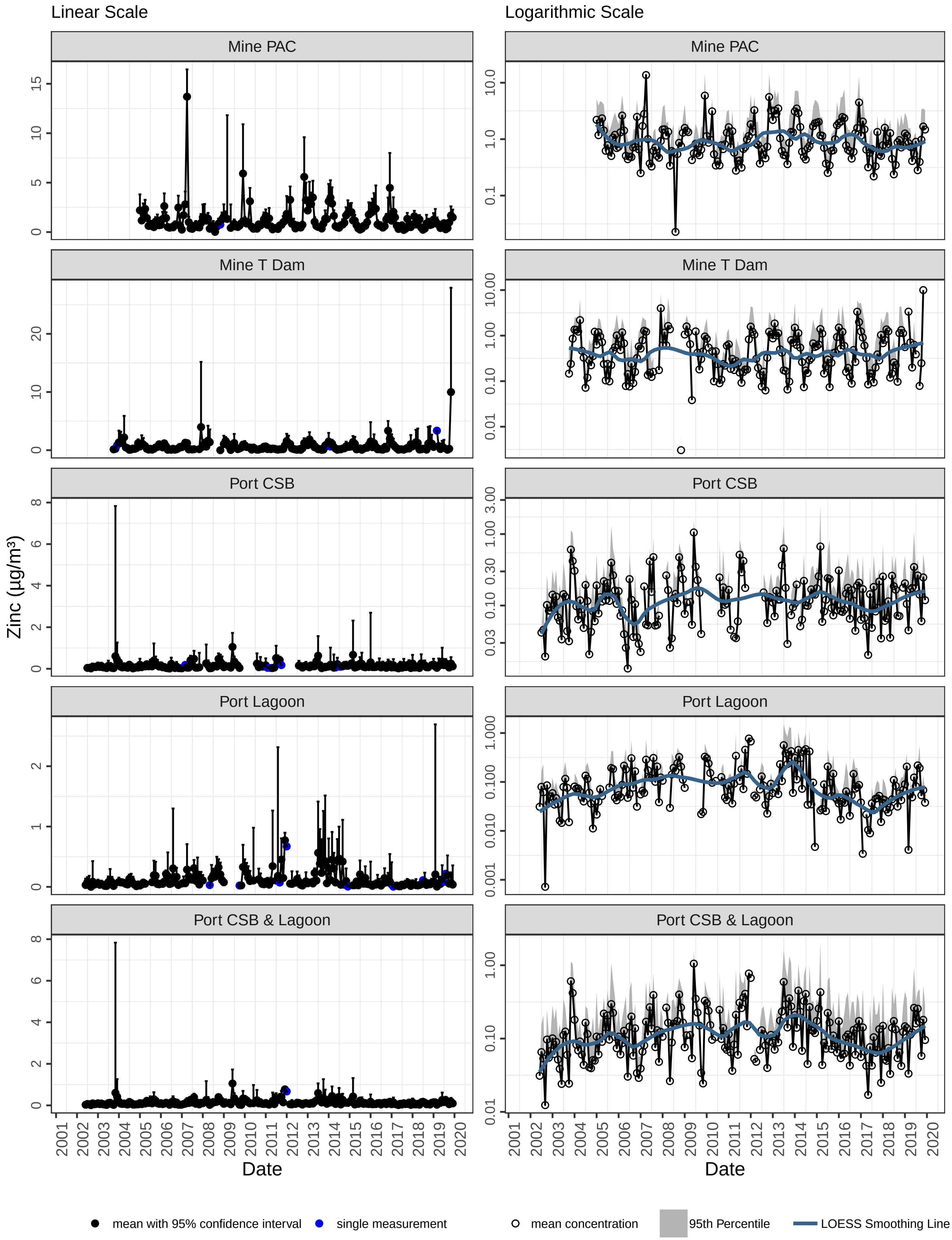


Figure 7. TEOM Zinc Concentration plots (all years)

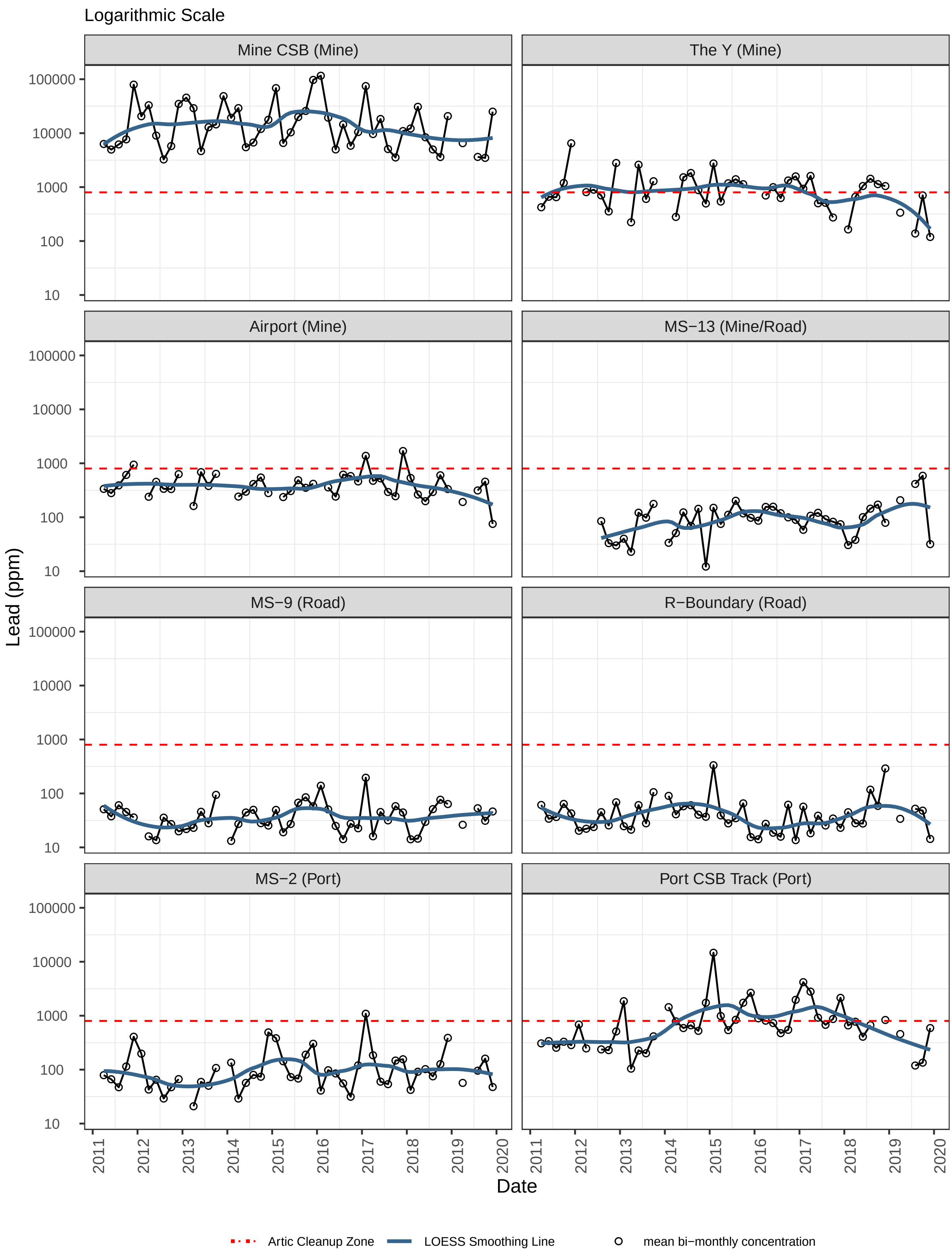


Figure 8. Road Surface Lead Concentration plots (all years)

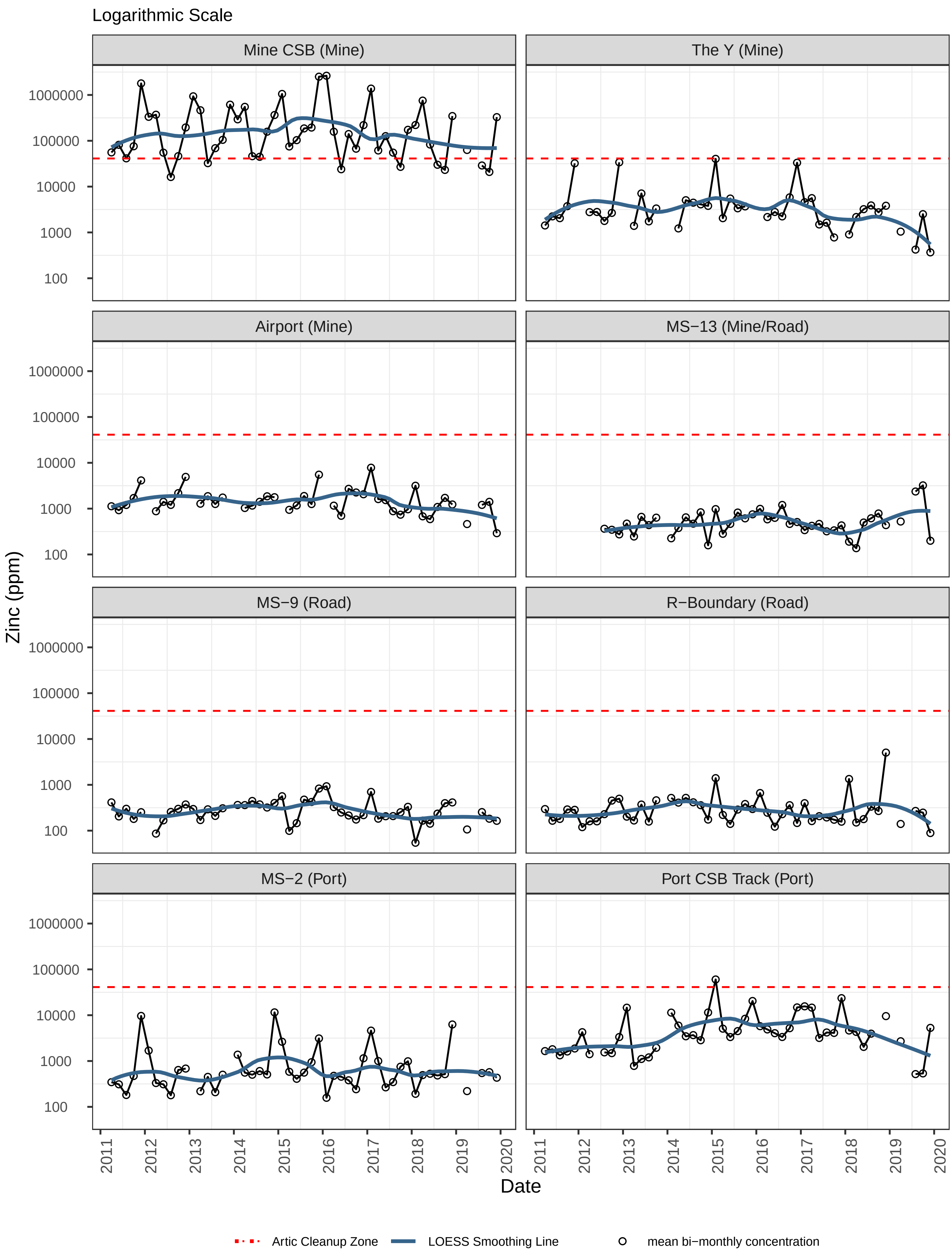


Figure 9. Road Surface Zinc Concentration plots (all years)

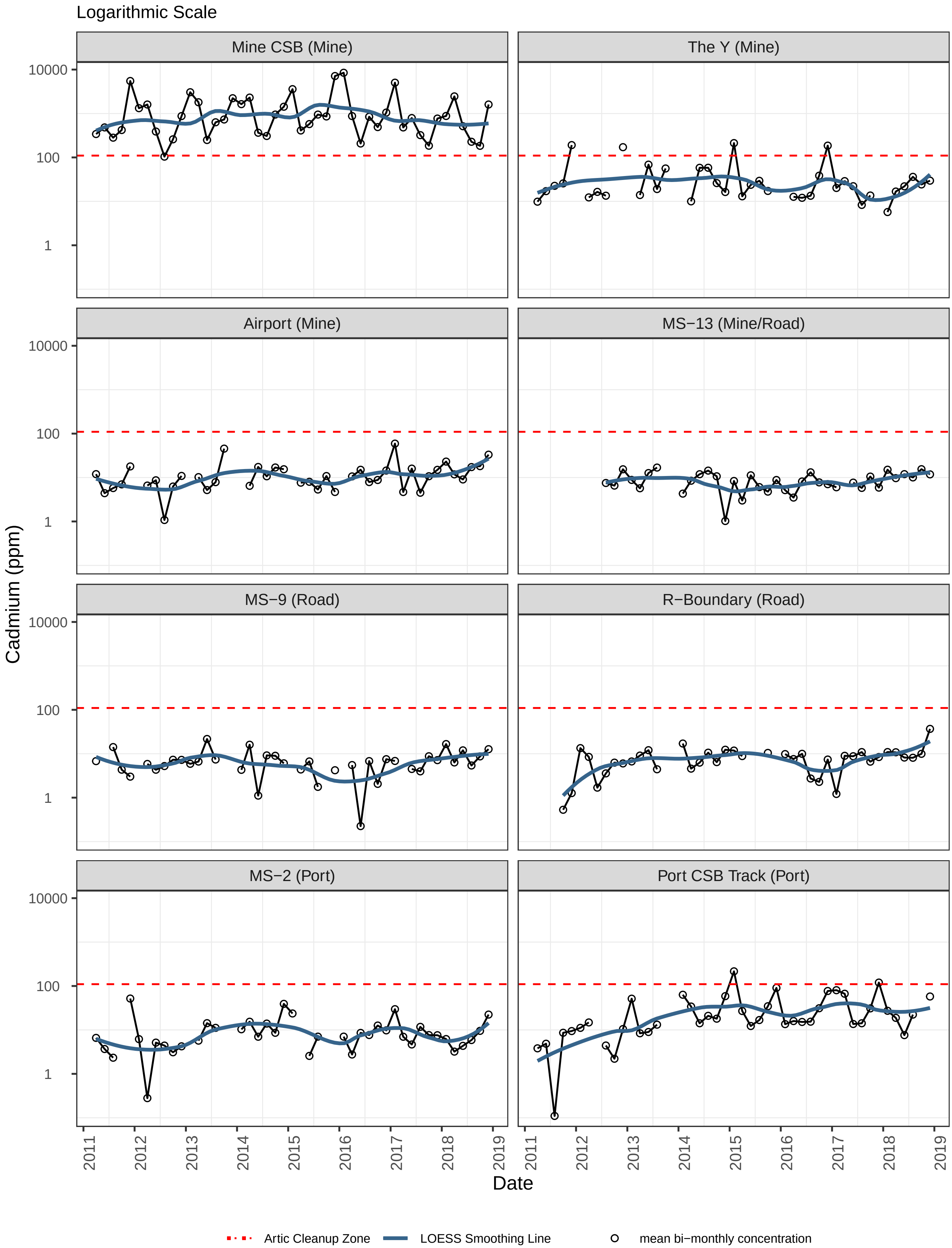


Figure 10. Road Surface Cadmium Concentration plots (all years)

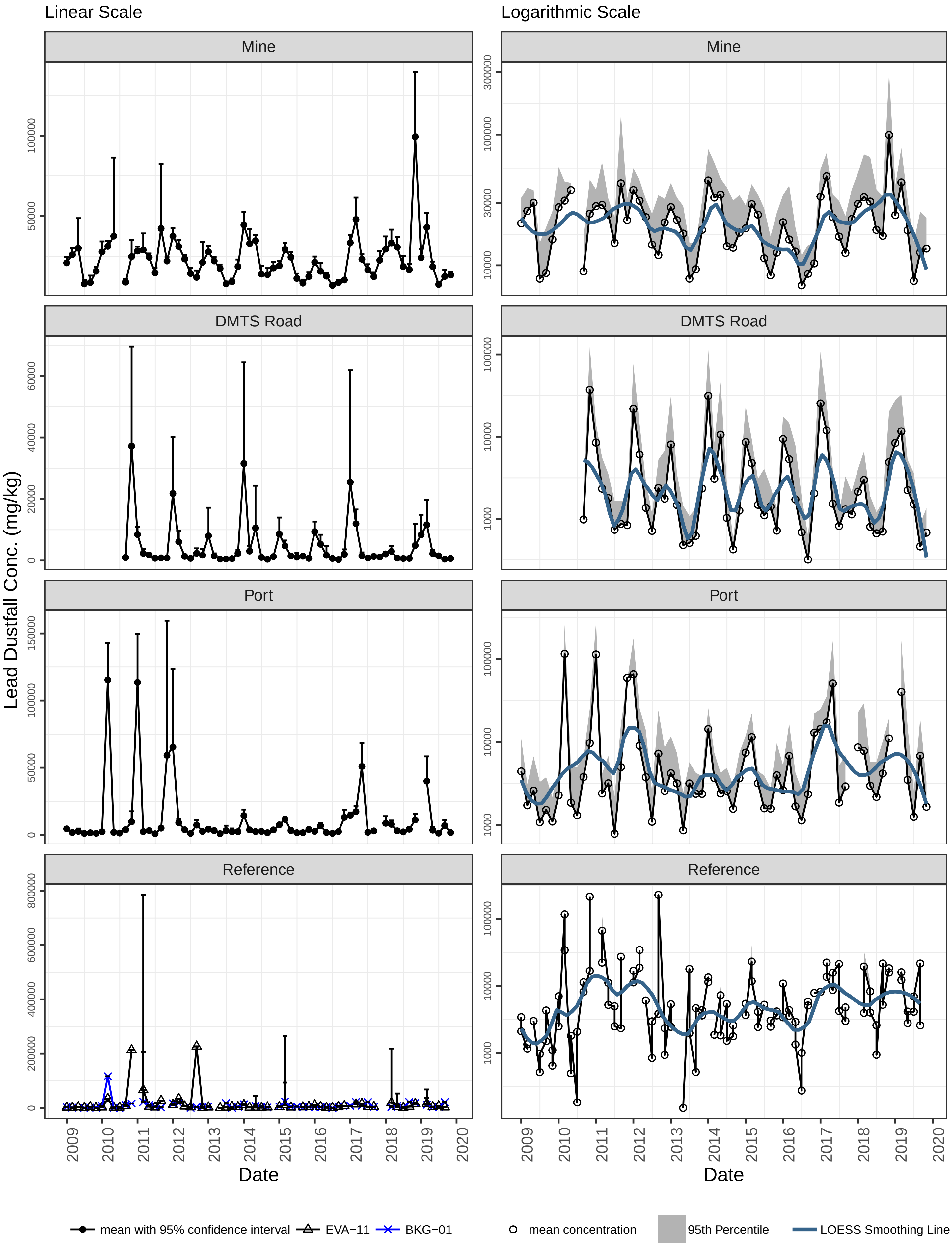


Figure 11. Dustfall Jars Lead Concentration plots (all years)

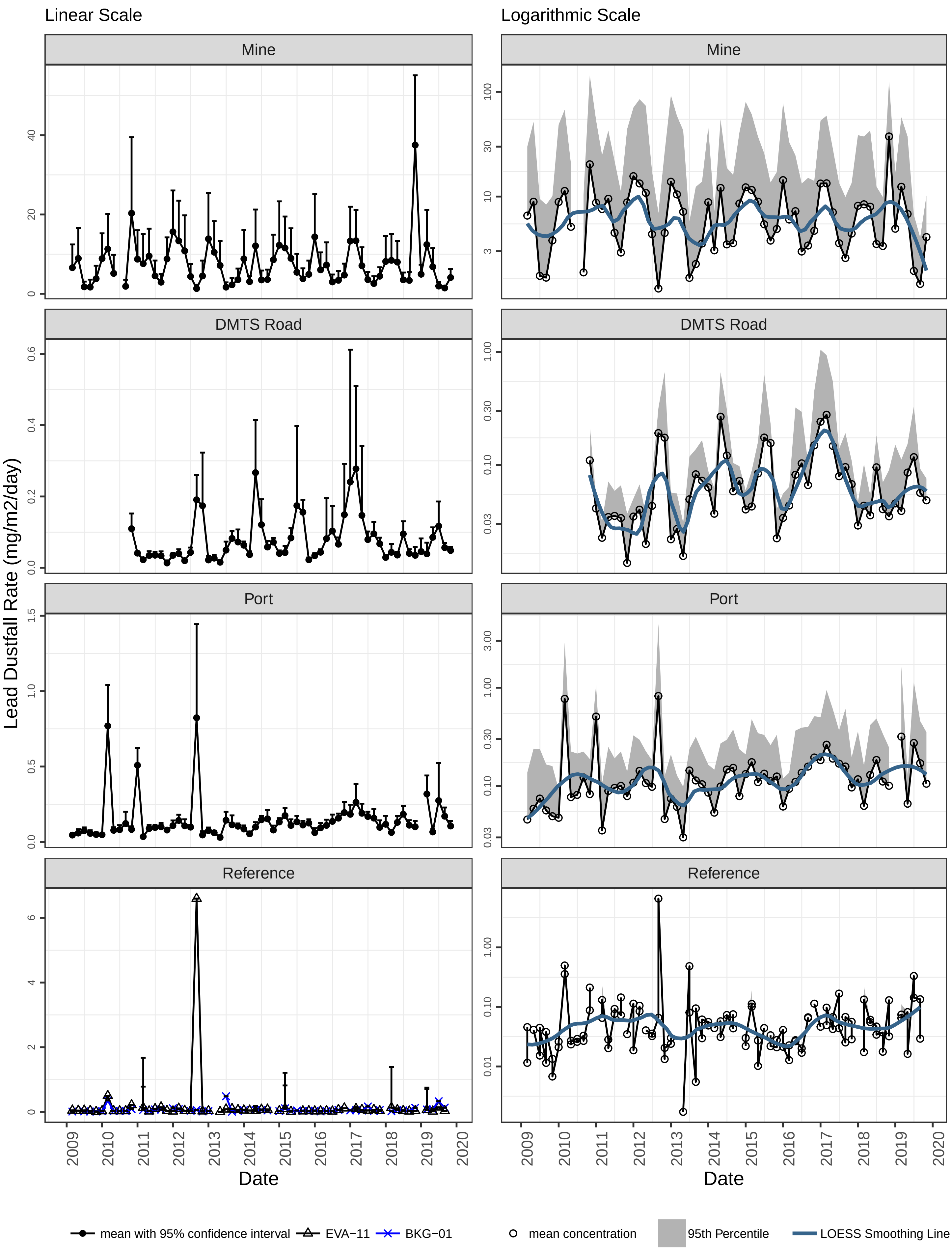


Figure 12. Dustfall Jars Lead Deposition Rate plots (all years)

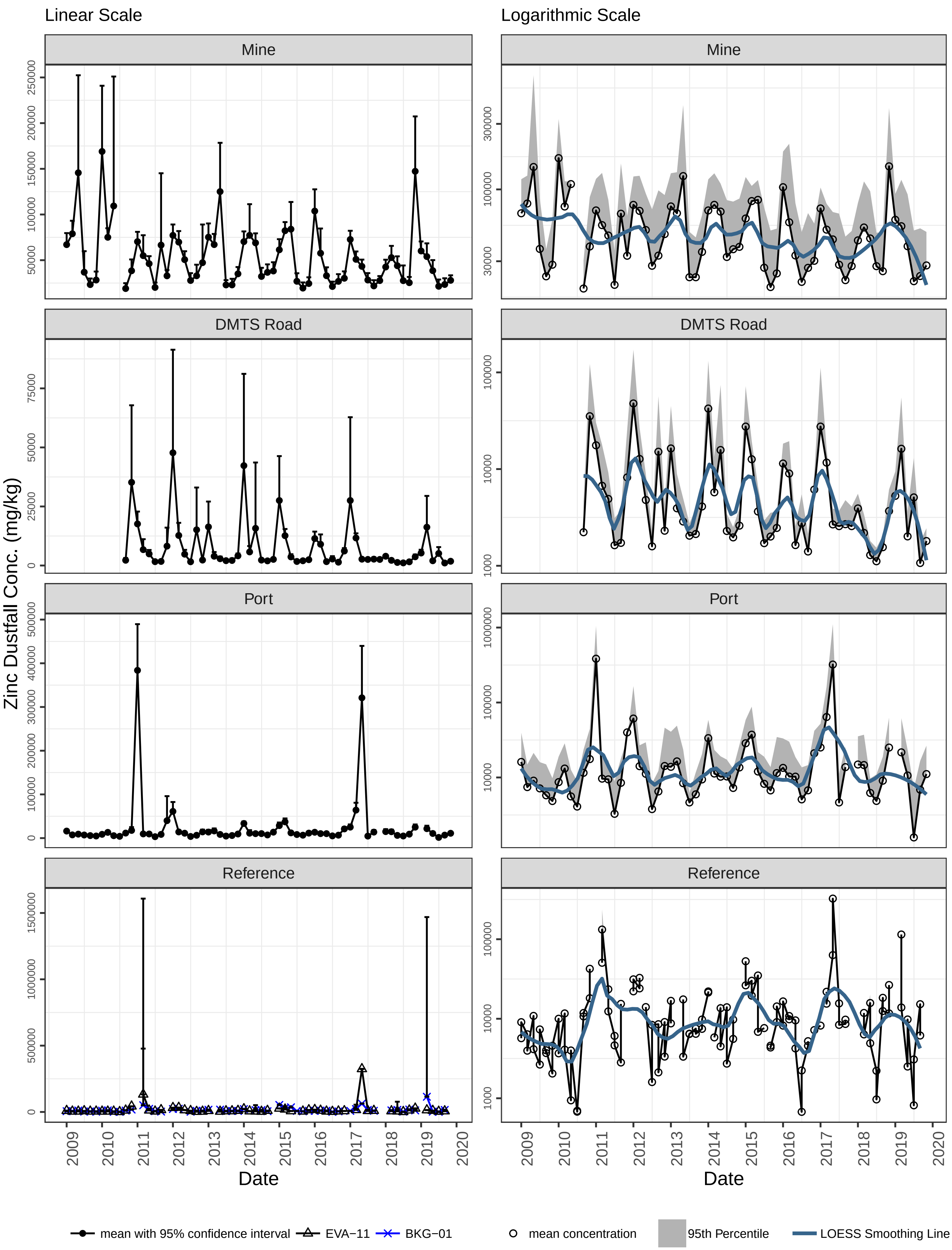


Figure 13. Dustfall Jars Zinc Concentration plots (all years)

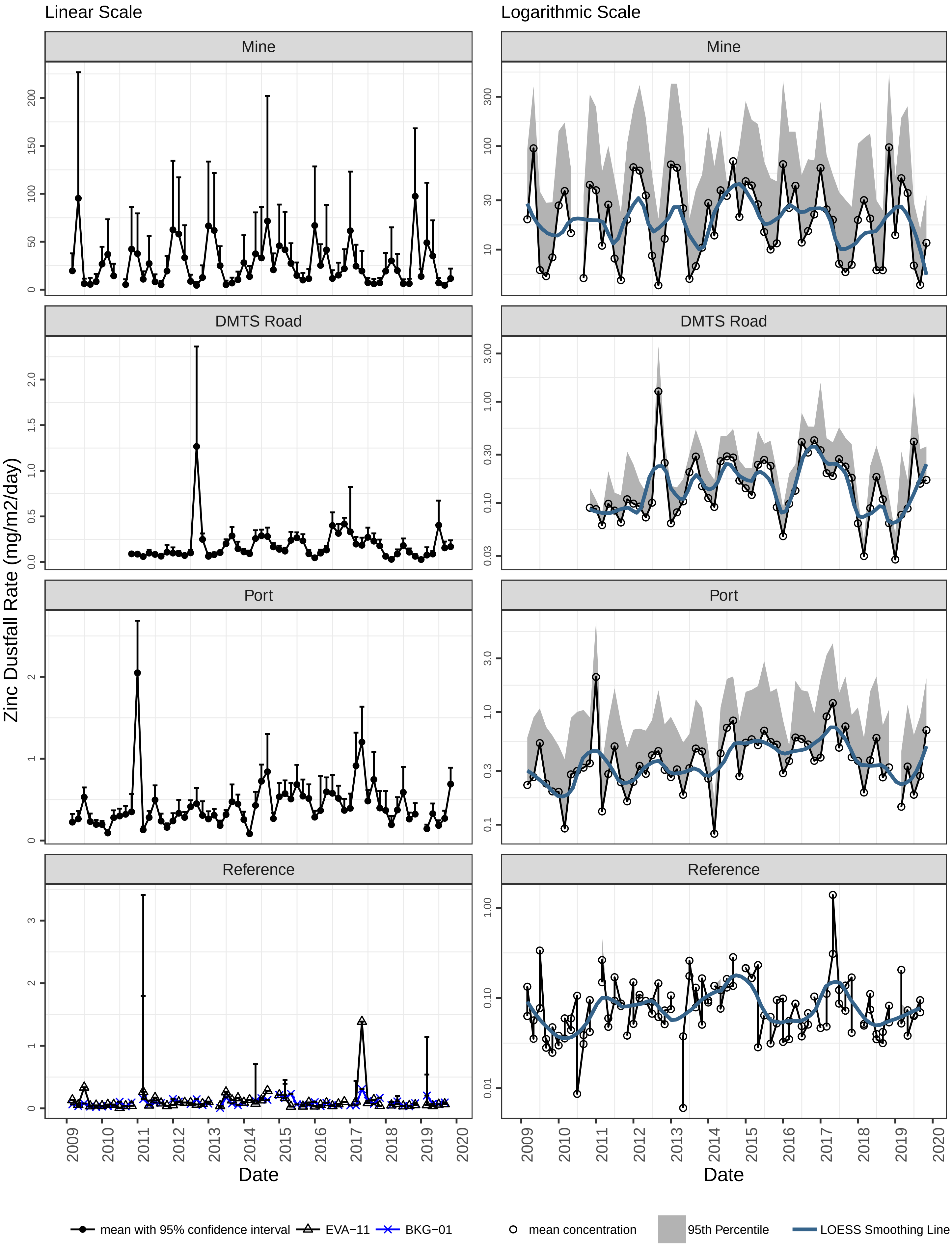


Figure 14. Dustfall Jars Zinc Deposition Rate plots (all years)

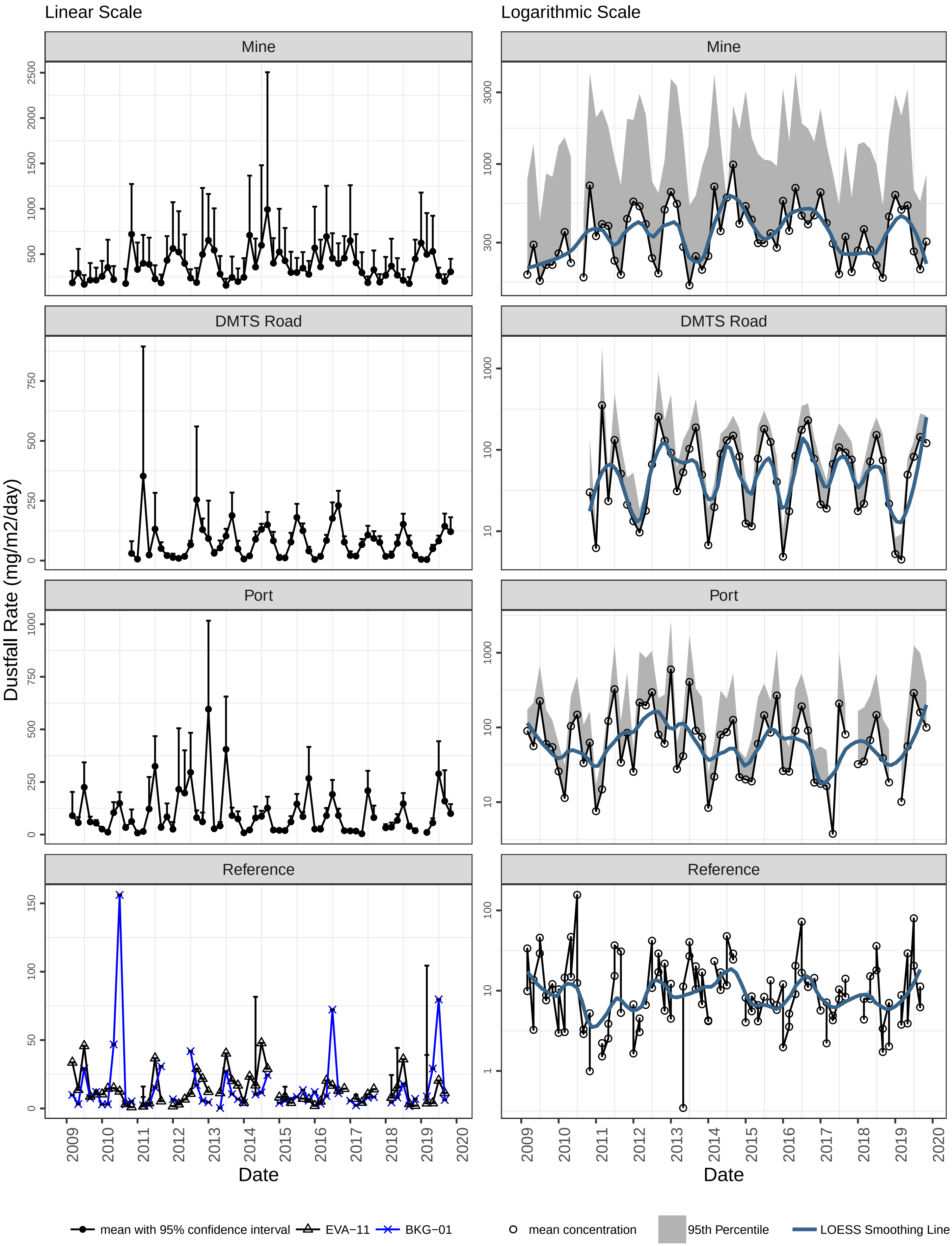


Figure 15. Dustfall Jars Solids Deposition Rate Plots

Table 1. TEOM concentration statistical trend analysis (Seasonal Mann Kendall Trend Test)

For 1/2016 - 12/2019; Mean Concentration

LEAD	Concentration ($\mu g/m^3$)		
	tau statistic	p value	significant trend?[a]
Mine PAC	-0.411	8.28E-07	Yes; Decreasing
Mine T Dam	-0.34	6.75E-05	Yes; Increasing
Port CSB	-0.298	3.85E-04	Yes; Increasing
Port Lagoon	-0.331	7.94E-05	Yes; Increasing
Port CSB & Lagoon	-0.321	1.15E-04	Yes; Increasing

ZINC	Concentration ($\mu g/m^3$)		
	tau statistic	p value	significant trend?[a]
Mine PAC	-0.405	1.19E-06	Yes; Decreasing
Mine T Dam	-0.321	1.69E-04	Yes; Increasing
Port CSB	-0.319	1.44E-04	Yes; Increasing
Port Lagoon	-0.313	1.92E-04	Yes; Increasing
Port CSB & Lagoon	-0.339	4.67E-05	Yes; Increasing

[a] Significant at p<0.05/2 (i.e., p<0.025 with Bonferroni adjustment because multiple [2] related hypotheses are tested).

For 1/2016 - 12/2019; Top 95% concentration

LEAD	Concentration ($\mu g/m^3$)		
	tau statistic	p value	significant trend?[a]
Mine PAC	-0.429	0.000000271	Yes; Decreasing
Mine T Dam	-0.359	0.0000257	Yes; Decreasing
Port CSB	-0.307	0.000256	Yes; Increasing
Port Lagoon	-0.356	0.0000228	Yes; Decreasing
Port CSB & Lagoon	-0.369	0.00000949	Yes; Decreasing

ZINC	Concentration ($\mu g/m^3$)		
	tau statistic	p value	significant trend?[a]
Mine PAC	-0.399	0.0000017	Yes; Decreasing
Mine T Dam	-0.34	0.0000675	Yes; Increasing
Port CSB	-0.343	0.000043	Yes; Increasing
Port Lagoon	-0.313	0.000192	Yes; Increasing
Port CSB & Lagoon	-0.327	0.0000855	Yes; Increasing

[a] Significant at p<0.05/2 (i.e., p<0.025 with Bonferroni adjustment because multiple [2] related hypotheses are tested).

Table 2. Road surface concentration statistical trend analysis (Seasonal Mann Kendall Trend Test)

For 1/2016 - 12/2019; Mean concentration:

LEAD		Concentration (ppm)		
		tau statistic	p value	significant trend?[a]
Mine[b]	Only years 2016 - 2019	-0.273	2.48E-02	No
Port		-0.416	6.24E-04	Yes; Decreasing
Road		-0.299	1.39E-02	Yes; Decreasing
Airport (Mine)		-0.405	1.03E-03	Yes; Decreasing
Mine CSB (Mine)		-0.026	8.31E-01	No
MS-13 (Mine/Road)		-0.351	3.90E-03	Yes; Decreasing
MS-2 (Port)		-0.299	1.39E-02	Yes; Decreasing
MS-9 (Road)		-0.273	2.48E-02	No
Port CSB Track (Port)		-0.415	7.71E-04	Yes; Decreasing
R-Boundary (Road)		-0.273	2.48E-02	No
The Y (Mine)		-0.390	1.88E-03	Yes; Decreasing

ZINC		Concentration (ppm)		
		tau statistic	p value	significant trend?[a]
Mine[b]	Only years 2016 - 2019	0.286	1.87E-02	No
Port		-0.442	2.78E-04	Yes; Decreasing
Road		-0.364	2.76E-03	Yes; Decreasing
Mine CSB (Mine)		0.727	2.14E-09	Yes; Increasing
The Y (Mine)		-0.319	1.10E-02	Yes; Decreasing
Airport (Mine)		-0.405	1.03E-03	Yes; Decreasing
MS-13 (Mine/Road)		-0.364	2.76E-03	Yes; Decreasing
MS-9 (Road)		-0.377	1.93E-03	Yes; Decreasing
R-Boundary (Road)		-0.364	2.76E-03	Yes; Decreasing
MS-2 (Port)		-0.312	1.03E-02	Yes; Decreasing
Port CSB Track (Port)		-0.388	1.68E-03	Yes; Decreasing

CADMIUM[c]		Concentration (ppm)		
		tau statistic	p value	significant trend?[a]
Mine[b]	Only years 2016 - 2018	-0.444	2.16E-03	Yes; Decreasing
Port		-0.400	5.76E-03	Yes; Decreasing
Road		-0.267	6.57E-02	No
Mine CSB (Mine)		-0.467	1.28E-03	Yes; Decreasing
The Y (Mine)		-0.375	1.32E-02	Yes; Decreasing
Airport (Mine)		-0.318	3.19E-02	No
MS-13 (Mine/Road)		-0.294	4.69E-02	No
MS-9 (Road)		-0.300	4.75E-02	No
R-Boundary (Road)		-0.311	3.18E-02	No
MS-2 (Port)		-0.444	2.16E-03	Yes; Decreasing
Port CSB Track (Port)		-0.412	5.41E-03	Yes; Decreasing

[a]Significant at $p<0.05/3$ (i.e., $p<0.017$ with Bonferroni adjustment because multiple [3] related hypotheses are tested)

[b]MS-13 included in Mine

[c]No Cadmium data for 2019, only years 2016-2018

Table 3. Dustfall rate and concentration statistical trend analysis (seasonal Mann Kendall trend test)

For 1/2016 - 12/2019; Mean Deposition Rate and Concentration:

LEAD	Dustfall Desposition Rate ($mg/m^2/day$)			Concentration (mg/kg-total solid)		
	tau statistic	p value	significant trend?[a]	tau statistic	p value	significant trend?[a]
Mine	-0.440	1.86E-04	Yes; Decreasing	0.333	4.68E-03	Yes; Increasing
DMTS Road	-0.405	5.94E-04	Yes; Decreasing	-0.321	6.38E-03	Yes; Decreasing
Port	-0.292	1.47E-02	Yes; Decreasing	-0.130	2.85E-01	No
Reference	-0.270	2.86E-02	No	-0.254	4.35E-02	No

ZINC	Dustfall Desposition Rate ($mg/m^2/day$)			Concentration (mg/kg-total solid)		
	tau statistic	p value	significant trend?[a]	tau statistic	p value	significant trend?[a]
Mine	-0.417	4.07E-04	Yes; Decreasing	0.762	1.01E-10	Yes; Increasing
DMTS Road	-0.452	1.24E-04	Yes; Decreasing	-0.345	3.40E-03	Yes; Decreasing
Port	-0.404	7.39E-04	Yes; Decreasing	-0.039	7.48E-01	No
Reference	-0.324	8.63E-03	Yes; Decreasing	-0.056	6.54E-01	No

TOTAL SOLIDS	Dustfall Desposition Rate ($mg/m^2/day$)		
	tau statistic	p value	significant trend?[a]
Mine	-0.381	1.23E-03	Yes; Decreasing
DMTS Road	-0.417	4.07E-04	Yes; Decreasing
Port	-0.325	7.53E-03	Yes; Decreasing
Reference	-0.296	1.85E-02	No

[a] Significant at $p<0.05/3$ (i.e., $p<0.017$ with Bonferroni adjustment because multiple [3] related hypotheses are tested).

For 1/2016 - 12/2019; Top 95% Deposition Rate and Concentration:

LEAD	Dustfall Desposition Rate ($mg/m^2/day$)			Concentration (mg/kg-total solid)		
	tau statistic	p value	significant trend?[a]	tau statistic	p value	significant trend?[a]
Mine	-0.429	2.76E-04	Yes; Decreasing	0.679	8.52E-09	Yes; Increasing
DMTS Road	-0.393	8.58E-04	Yes; Decreasing	-0.083	4.80E-01	No
Port	-0.304	1.10E-02	Yes; Decreasing	0.195	1.09E-01	No
Reference	-0.23	6.28E-02	No	0.099	4.32E-01	No

ZINC	Dustfall Desposition Rate ($mg/m^2/day$)			Concentration (mg/kg-total solid)		
	tau statistic	p value	significant trend?[a]	tau statistic	p value	significant trend?[a]
Mine	-0.440	1.86E-04	Yes; Decreasing	0.762	1.01E-10	Yes; Increasing
DMTS Road	-0.440	1.86E-04	Yes; Decreasing	-0.226	5.49E-02	No
Port	-0.379	1.54E-03	Yes; Decreasing	0.416	6.24E-04	Yes; Increasing
Reference	-0.338	6.22E-03	Yes; Decreasing	0.070	5.75E-01	No

TOTAL SOLIDS	Dustfall Desposition Rate ($mg/m^2/day$)		
	tau statistic	p value	significant trend?[a]
Mine	-0.393	8.58E-04	Yes; Decreasing
DMTS Road	-0.429	2.76E-04	Yes; Decreasing
Port	-0.312	1.03E-02	Yes; Decreasing
Reference	-0.268	3.31E-02	No

[a] Significant at $p<0.05/3$ (i.e., $p<0.017$ with Bonferroni adjustment because multiple [3] related hypotheses are tested).

Table 4. Summary of dust monitoring trends

For most recent 4 years (2016-2019)

Location and Measure	Road Surface (Concentration)		
	Mean		
	Pb	Zn	Cd[c]
Mine[b] (Conc.)	—	—	↘
Road (Conc.)	↘	↘	—
Port (Conc.)	↘	↘	↘

Location and Measure	TEOM (Air Concentration)			
	Mean		95[th] Percentile	
	Pb	Zn	Pb	Zn
Mine PAC (Conc.)	↘	↘	↘	↘
Mine TDam (Conc.)	↗	↗	↘	↗
Port CSB (Conc.)	↗	↗	↗	↗
Port Lagoon (Conc.)	↗	↗	↘	↗
Port CSB & Lagoon (Conc.)	↗	↗	↘	↗

Location and Measure	Dustfall Jars (Concentration and Desposition Rate)					
	Mean			95th Percentile		
	Pb	Zn	Solids	Pb	Zn	Solids
Mine (Conc.)	↗	↗	a	↗	↗	a
Mine (Rate)	↘	↘	↘	↘	↘	↘
Road (Conc.)	↘	↘	a	—	—	a
Road (Rate)	↘	↘	↘	↘	↘	↘
Port (Conc.)	—	—	a	—	↗	a
Port (Rate)	↘	↘	↘	↘	↘	↘
Reference (Conc.)	—	—	a	—	—	a
Reference (Rate)	—	↘	—	—	↘	—

[a] Concentration is not evaluated for solids, because total solids is the entire sample mass.

[b] MS-13 included in Mine

[c] No Cadmium data for 2019, only years 2016-2018

1. Results are summarized from statistical test results in Tables x, x, and x for air concentrations, road surface concentrations, concentrations in dustfall, and dustfall rates, respectively.
2. Results are presented for statistical testing using data from the past four years.

Notes:

— Indicates no statistically significant change over time period tested (trend is FLAT).

↗ Indicates a statistically significant increase over time period tested (trend is UP).

↘ Indicates a statistically significant decrease over time period tested (trend is DOWN).

TEOM = tapered element oscillating microbalance (air sampling device)
Conc = air concentration (TEOM air sampling) or concentration in dustfall (dustfall jars)
Rate = dustfall deposition rate based on dustfall jar measurements

Tdam = mine tailings dam
PAC = personnel accommodations complex
CSB = concentrate storage building

Appendix A: Dust Reduction Study

January 20, 2019
Envirokleen EK-2800 Effectiveness Study for DMTS Port Road Dust Control

INTRODUCTION

Red Dog Operations (operated by Teck Alaska) located in Northwest Alaska, is one of the largest zinc and lead concentrate mines in the world that mills ore into concentrate and ships to worldwide markets from the Red Dog Port on the Chuckchi Sea. The mine utilizes the DeLong Mountain Transportation System (DMTS) Road (Port Road), an approximately 50- mile gravel road, to transport concentrate and materials between the Red Dog Port (port) and the mine. Teck has utilized water and calcium chloride ($CaCl_2$) to control fugitive dust generated from the road surface for driver safety and to protect the adjacent habitat.

RDO is continually trying to improve upon past performance related to fugitive dust while remaining in compliance with all regulatory permits, conditions and agreements in place with stakeholders in the region. As part of that mission, in 2018, RDO performed a study to evaluate the cost-effectiveness and performance of Envirokleen2800 (EK-2800), a semi-permanent fines stabilization (dust suppressant) product manufactured by Midwest Industrial Supply (Midwest).

The purpose of the study was to compare fugitive dust emissions generated by mobile equipment (primarily haul truck traffic, but also some light vehicles) on two separate potions of the Port Road: one part treated with EK2800 (the “Test Section”), and another part treated with calcium chloride, which is the product that is that has been used for multiple years (the “Control Section”). The Control Section was treated exactly as the rest of the entire port haul road. The calcium chloride solution is spread approximately three times during the summer months, and the road is watered a few times per week. In contrast, the EK-2800 product is mixed in with the road gravel using water; interim watering is not needed after application of EK-2800.

METHODS

Prior to beginning the study, approval to test the EK-2800 was granted by Alaska Department of Environmental Conservation (Alternative Road Dust Suppressant Permit Number AQ0290TVP02 Rev.1 File No. 475.16.011).

The Red Dog Surface Crew is responsible for treating and maintaining the DMTS road for travel and transport of materials from the mine to the port and vice versa. On June 21, 2018, the surface crew prepared the Test Section according to Midwest’s specifications for grading and watering. On June 22, 2018, under guidance from Bill Chapple at Midwest , the surface crew used Midwest’s ESprayer system (Figure 1) to apply 22,000-gallons of EK-2800 dust suppressant, in multiple passes, to yield a final application rate of 1 gallon per 40-ft^2, or 1:40 on the Test Section.

The Test Section covered 3.5 miles of the Port Road, from Mile 28 to Mile 31.5 (Figure 2). The EK-2800 was applied to an approximately 30-feet wide section of the road surface, but the road shoulders were not treated. Three additional “light maintenance” applications were applied that consisted of a single pass at one-fifth of the final application rate, or 1:200. The three maintenance applications were applied at three-week intervals after the first application.

The Test Section was relatively straight and was selected because trucks typically gain speed on that portion of the road, creating favorable conditions for fugitive dust production. The Control Section, which was located between Mileposts 36 and 39.5, was also relatively straight and mimicked conditions for the Test Section.

The study utilized Tisch Model 5170V high-volume active air samplers (air samplers) and dustfall jars located on the tundra adjacent to the Port Road. A total of six air samplers were deployed to six locations along the Port Road. All units were located 10 feet from the road on the north side in the tundra and were powered by Honda generators intended to sample continuously for approximately 24-hours. Samples were collected on 8-inch by 10-inch quartz fiber filters and analyzed by NIOSH 7300M (modified for air) for the following:

- Total suspended particulates (TSP)
- Crustal elements: aluminum (Al), barium (Ba), calcium (Ca), iron (Fe)
- Target metals: cadmium (Cd), lead (Pb), zinc (Zn)

In addition to the high volume air samplers, twelve dustfall jars were deployed to measure deposition rates for lead, zinc, and total solids; six were deployed in the Test Section (Mile Markers 28 through 31.5), and the other six were deployed in the Control Section (Mile Markers 36 through 39.5). The jars were located 100 meters north of the road at every half mile. The jars were set out for dust collection on July 16, 2018, and final collection dates were September 22, 2018 for the Test Section and September 23, 2018 for the Control Section.

RESULTS

Results from both the dustfall jars and the high volume samplers clearly indicated that the EK-2800 dust suppressant product was not as effective as calcium chloride at suppressing fugitive dust generated by traffic on the Port Road. Results of the dustfall jars show that zinc, lead and total solids deposition rates were less for the Control Section than for the Test Section. In some cases, the EK-2800 product actually yielded higher deposition rates in the Test Section.

As presented in Figures 3, 4, and 5 below, there was no detected decrease in fugitive dust from the Test Section when compared to the Control Section. The EK-2800 product did not meet expectations for dust control, although it performed well at other sites in the Canadian Arctic per the manufacturer, and despite the high cost of the EK-2800 product compared to the calcium chloride.

Similar results were found using the high volume dust samplers. Although there were some project challenges involved with the dust samplers, four of the six samplers[1] were able to yield enough data during sampling events on 11 August 2018, 18 August 2018, 15 August 2018, and 20 August 2020 to allow comparison between the Test Section and Control Section of the road (Figure 6).

As can be seen from this figure, there is very little difference in concentrations of target metals (cadmium, lead, and zinc) from the Test Section (MP 29 and MP 30) and the Control Section (MP 38 and MP39). Similar to the results from the dustfall jars, the results from the high volume samplers indicate that EK-2800 was not as effective at reducing dust concentrations when compared to the calcium chloride and water applications that are currently applied to the Port Road.

CONCLUSIONS

[1] Although two additional high-volume samplers were deployed in the field, the data from those samplers were not available due to generator malfunction.

It is RDO's goal to continually improve on prevention and best management practices when possible. Although the calcium chloride has been used for years, the EK-2800 product was tested to determine if it could work more effectively to reduce fugitive dust from the road. This current study suggests that calcium chloride remains a superior method for road dust suppressant along the Port Road. If additional products are identified for future use, then RDO will request permission from Alaska Department of Environmental Conservation to test the product.

Figure 1 Photo of the ESprayer System. Totes containing EK-2800 loaded on the trailer.

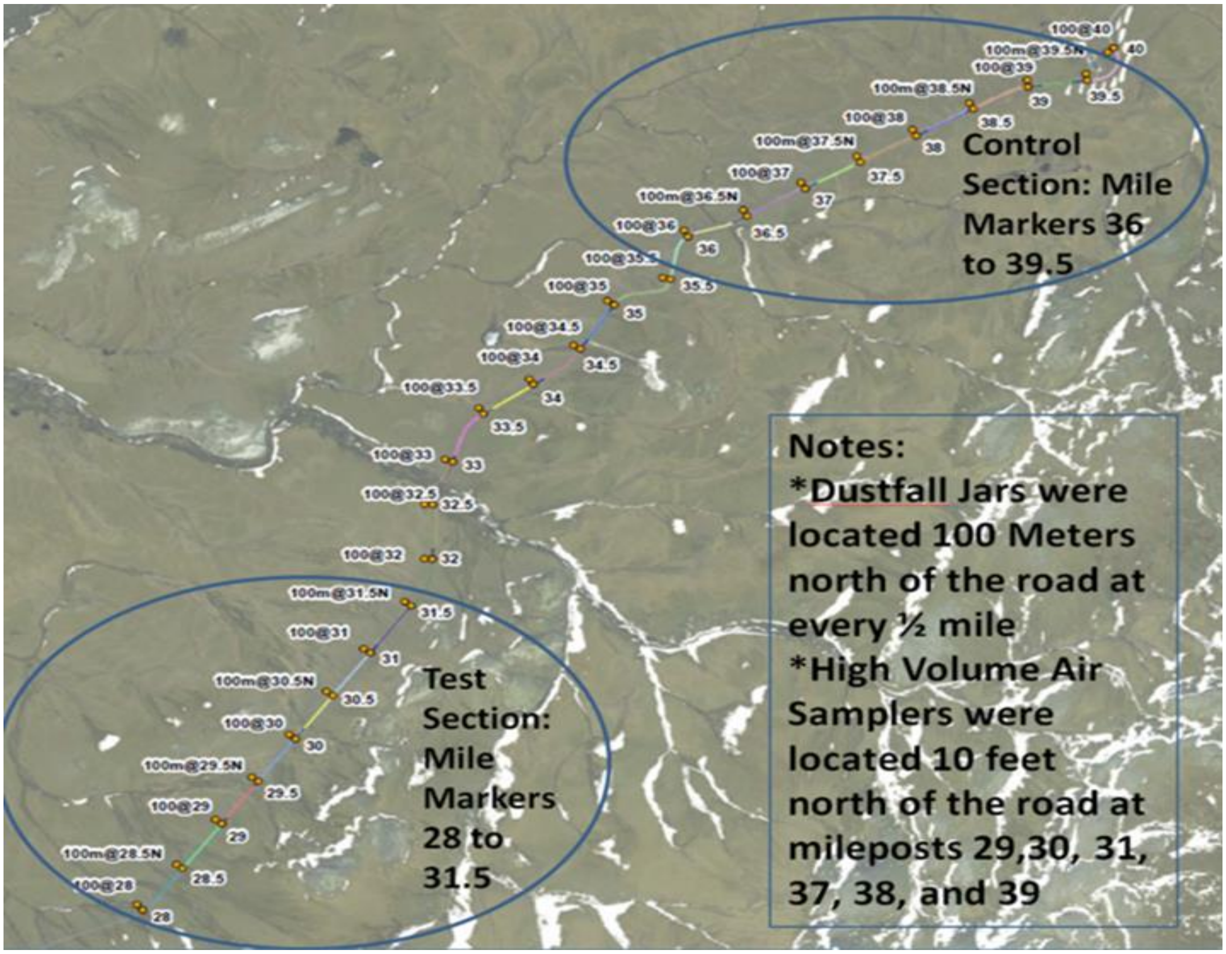


Figure 2. Map showing mile markers on DMTS Port Road, and designated Control and Test Sections.

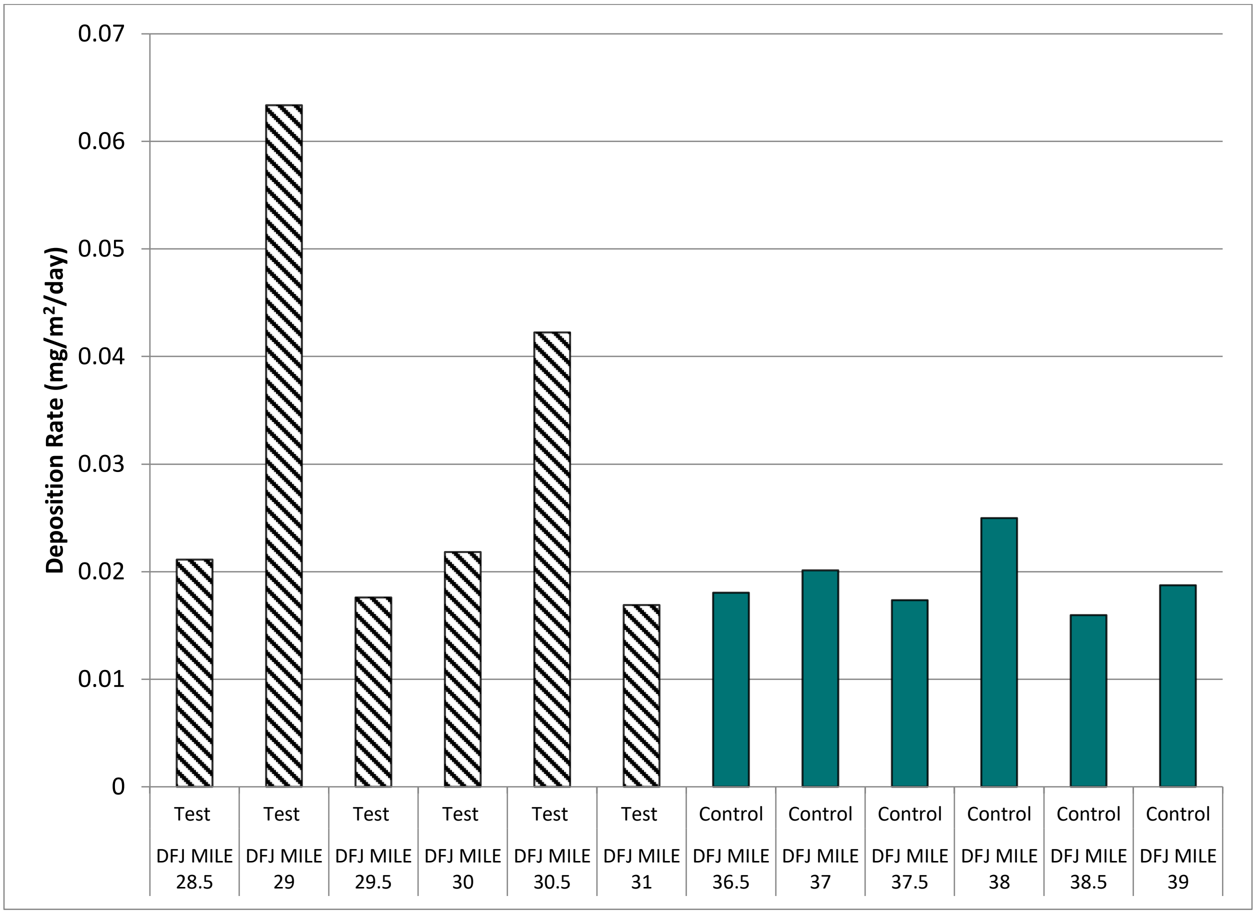


Figure 3. Dustfall Jar Results for Lead Deposition Rate

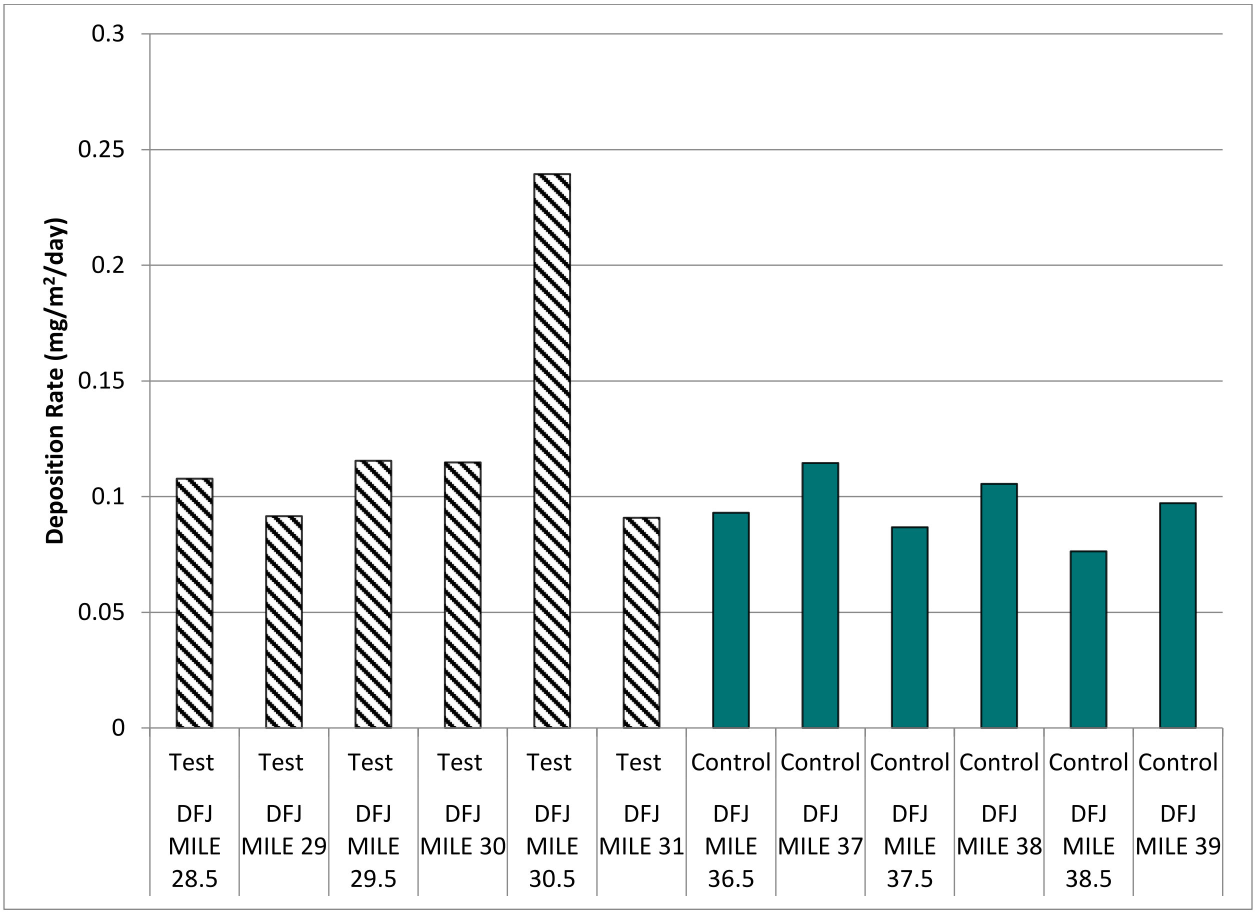


Figure 4. Dustfall Jar Results for Zinc Deposition Rate

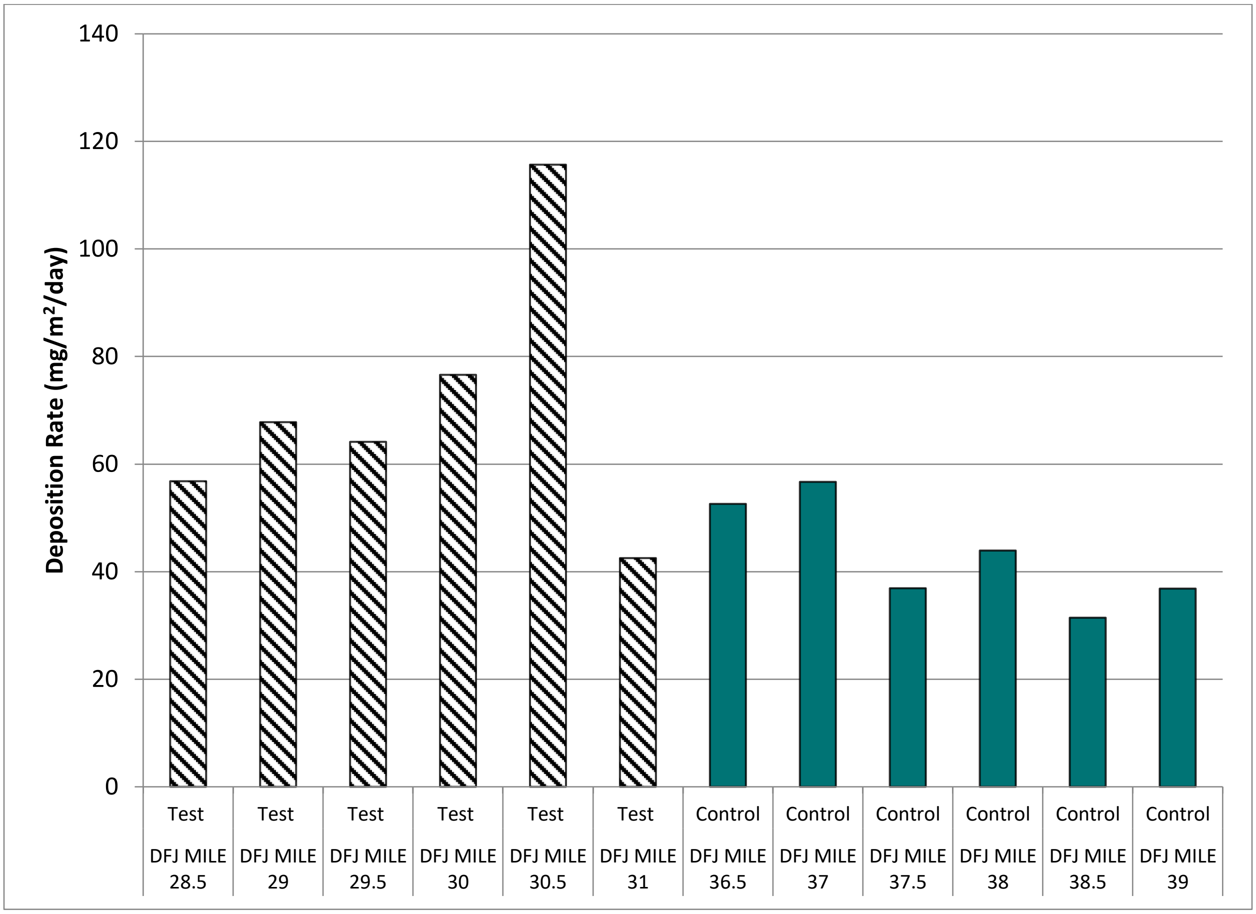
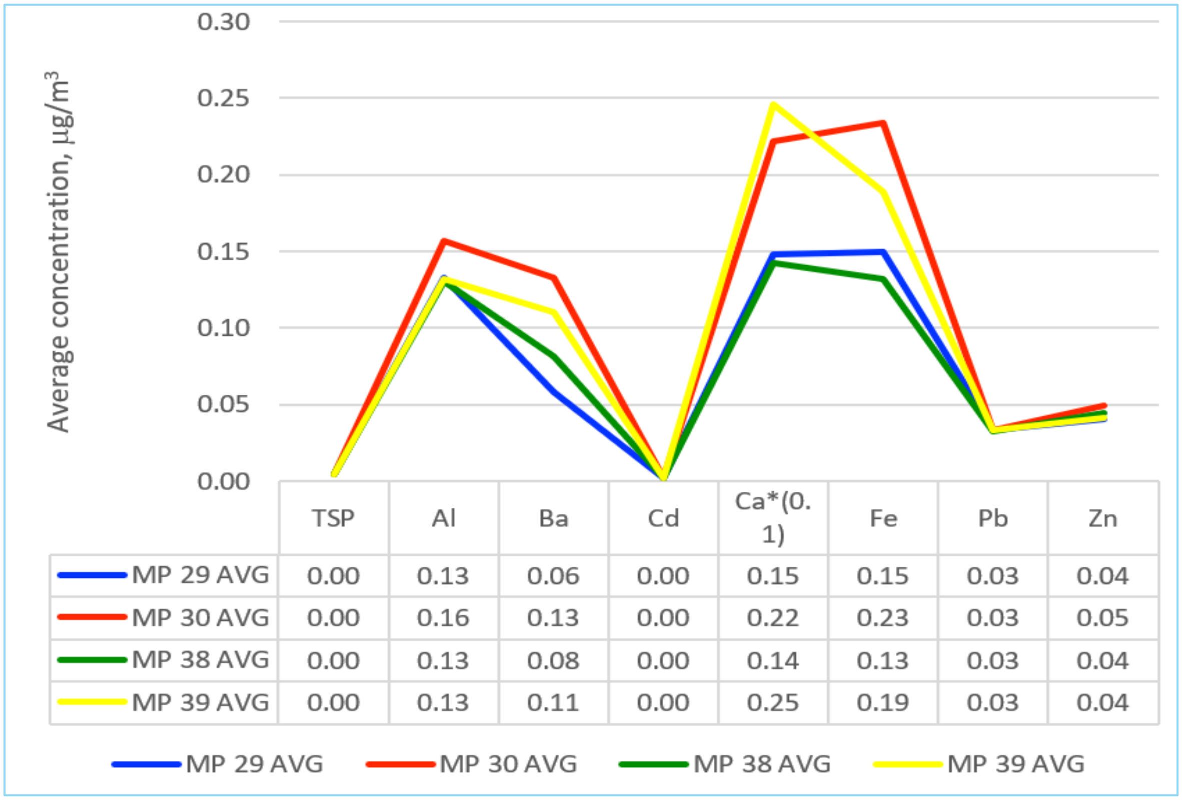


Figure 5. Dustfall Jar Results for Total Solids Deposition Rate



	TSP	Al	Ba	Cd	Ca*(0.1)	Fe	Pb	Zn
MP 29 AVG	0.00	0.13	0.06	0.00	0.15	0.15	0.03	0.04
MP 30 AVG	0.00	0.16	0.13	0.00	0.22	0.23	0.03	0.05
MP 38 AVG	0.00	0.13	0.08	0.00	0.14	0.13	0.03	0.04
MP 39 AVG	0.00	0.13	0.11	0.00	0.25	0.19	0.03	0.04

Figure 6. Comparison of average TSP and metals concentrations in high-volume samplers for four locations: Test Section at MP 29 and MP 30, and Control Section at MP 38 and 39.

Appendix B: Dust Reduction Study

Testing the Effectiveness of the New Red Dog Truck Unloading Building Air Wash System

Teck

Introduction

Red Dog Mine concentrate haul trucks deliver lead and zinc concentrate to the Truck Unloading Building ("TUB") at the Red Dog Port. After the trucks enter the TUB, concentrate dust can become airborne when the side-dump style haul trucks dump concentrate into the TUB conveyor. The TUB is equipped with bag houses designed to collect this dust into a filtration system. After dumping, haul truck drivers have observed dust on their vehicles that could potentially be released to the tundra environment after the trucks exit the TUB.

Although installation of a wet wash system to remove dust from trucks would be ideal, given the cold arctic winters, it is not possible to use water during most of the year. Therefore, in June 2018, Teck installed an AirBlade air wash system to remove dust from truck surfaces as trucks exit the TUB. The AirBlade is a powerful blower, the same kind that is used in some car washes to dry vehicles as they exit the car wash. It consists of six blowers mounted to a rack approximately ten feet high inside the TUB, near the exit. Two of the blowers are top-mounted, side-by-side blowers, and four are vertically-mounted blowers (two on each side of the truck).

Photo 1. Six blowers installed inside the Truck Unloading Building.

Methods

In October 2018, a study was conducted to determine the effectiveness of the air wash system. Ghostwipes were used to collect samples from surfaces of 14 haul trucks. Seven trucks were sampled with the air wash system in operation and seven were sampled with the system turned off.
Two samples were collected from each truck: one sample from the truck hood on the passenger side and one from the passenger door. Surfaces were cleaned at the TUB entrance prior to the truck entering the TUB. The sample surfaces were washed with potable water obtained from the Port PAC kitchen and thick absorbent paper shop towels to remove visible road dust and mud debris. No detergents or solvents were used. Prior to sampling, the sample surfaces were wiped with wet shop towels and hand dried with dry shop towels.

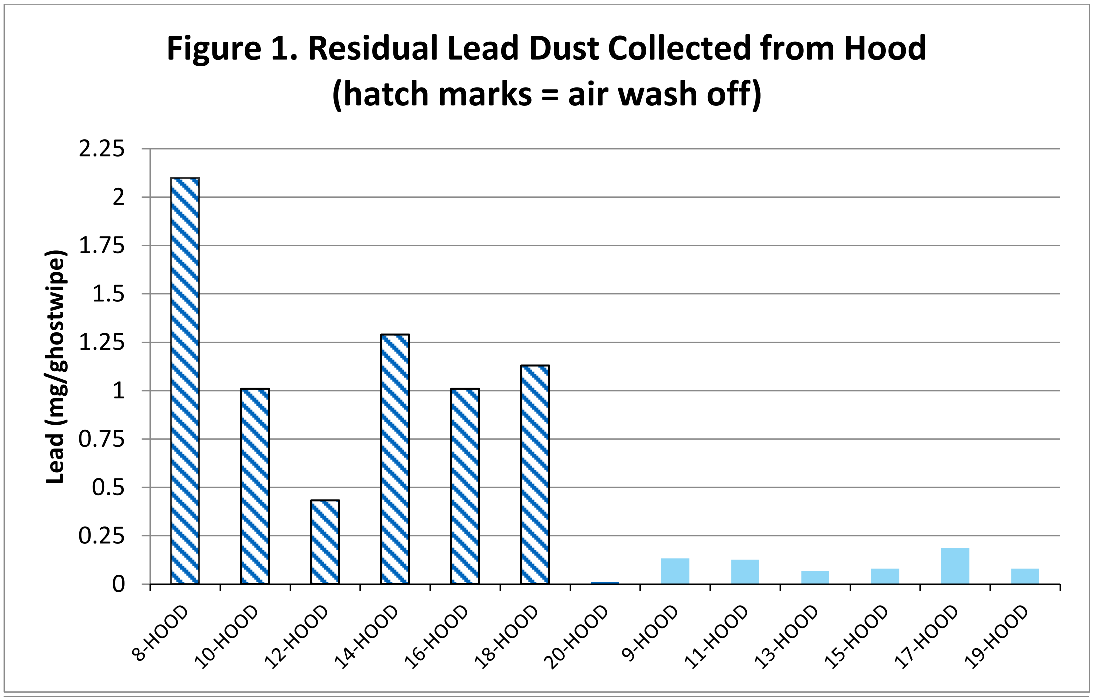
All surface dust samples were collected with one 15 cm by 15 cm (225 cm^2) GhostWipe pre-wetted (deionized water) sample wipe applied to an area equal to 900 cm^2 using a clean 30x30 cm sample template on each truck. All dust samples were collected per the ASTM D7707 protocol as described in the manufacturer's instructional video.

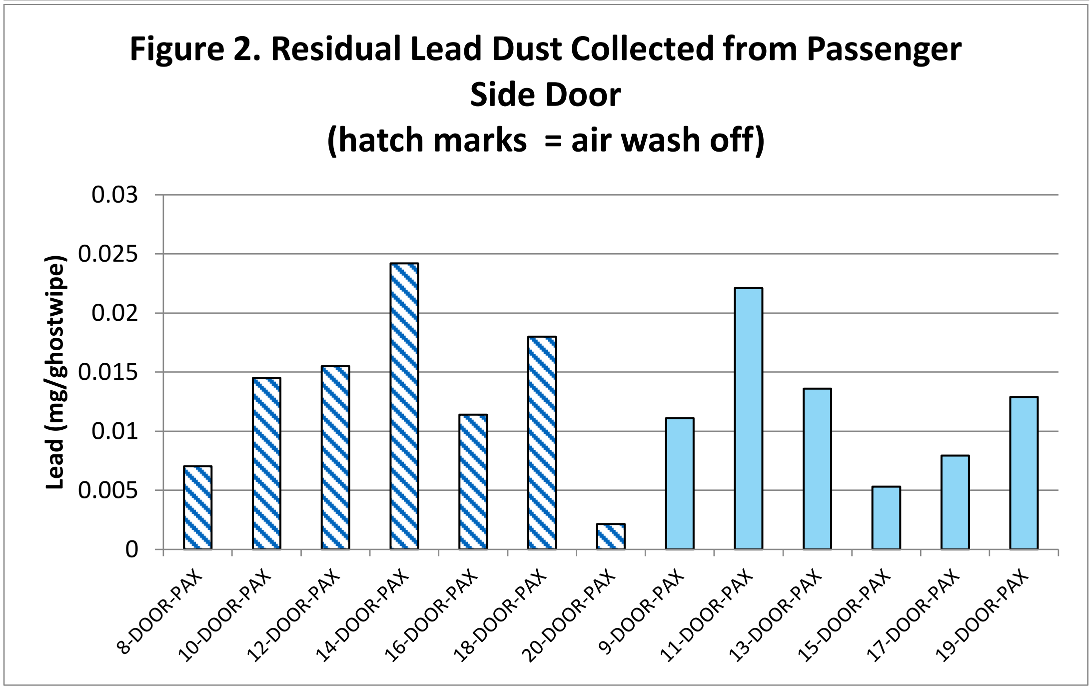
Photo 2. Placement of the sample template for the Ghostwipe on the passenger door of the truck.

Results

A thin layer of dust was visibly present on trucks exiting the TUB. However, the dust cover was heavier when the air wash was not used. There was also a visibly higher accumulation of dust on the truck hoods than on the passenger doors. The door surfaces appeared to accumulate much less dust than the hood, regardless of air-washing.

When the trucks went through the air wash, there was a statistically significant reduction in lead concentrations on the hood of the vehicle (Figure 1). Lead concentrations did not significantly change on the passenger doors after going through the air wash (Figure 2). However, the lead concentrations on the passenger doors were an order of magnitude lower than those on the hoods of the trucks and therefore not a major accumulator of dust (compare Figure 1 and 2).





Discussion

The air wash proved to be effective at blowing the dust off the hoods of the trucks. Although the air wash appeared to have less effect on the doors, the doors accumulate significantly less dust (by an order of magnitude) than the hoods. Discussions with the port hopper operators and the NANA/Lynden drivers also suggested that dust is effectively removed from the trucks by the air wash. In the past, prior to the truck wash being installed, the drivers did not roll down their windows until they turned the curve of the racetrack because they did not want the dust from the truck to potentially blow back into their cab. The airwash allows the drivers to immediately open their windows after exiting the TUB during the summer months, offering another potential benefit to drivers in the summer months. Additional improvements to the system will be considered following discussions with port operators.

Evaluation of Metals Exposure from Consuming Meat, Marrow, Bone, and Broth in Soups Prepared with Arctic Caribou near Red Dog Mine

August 1, 2020

Teck

Evaluation of Metals Exposure from Consuming Meat, Marrow, Bone, and Broth in Soups Prepared with Arctic Caribou near Red Dog Mine

Table of Contents

Abstract

Red Dog Mine, located in the western Brooks Mountain Range, Alaska, is one of the richest zinc deposits in the world. The Western Arctic and Teshekpuk Lake caribou herds pass through and sometimes overwinter near Red Dog Operations (RDO). Caribou are an integral part of life for Alaska Natives for both subsistence food and cultural importance. Risk assessments were conducted by the Alaska Department of Public Health and Teck Alaska to evaluate subsistence consumption of meat, liver, and kidney from caribou collected near RDO. These assessments concluded that risks from subsistence consumption of caribou were within acceptable public health limits. As part of the ongoing RDO fugitive dust risk management plan, meetings were held with local community members who expressed concerns that caribou bones and bone marrow, which are traditionally consumed in soups, were not evaluated as part of the risk assessment process. Therefore, an investigation of metals extracted from cooked caribou bone, including the meat and marrow, was undertaken to address these concerns.

Caribou were harvested by local subsistence hunters near the DeLong Mountain Regional Transportation System (DMTS) road associated with RDO, and in Cape Krusenstern National Monument as a reference site. Water-, tomato-, and vinegar-based soups were prepared with bones, meat, and marrow from three food sources (i.e., wild caribou, commercial reindeer and beef). After cooking, there were no significant differences in lead concentrations between cooked and uncooked caribou meat, bone, and marrow. However, zinc and cadmium concentrations increased significantly in meat after cooking for caribou harvested both from RDO and the reference area. Lead concentrations in the reindeer and beef meat, marrow, and bone were also unaffected by cooking, while zinc concentrations in reindeer and beef meat increased after cooking, similar to the findings for caribou. The results for cadmium were inconclusive due to a large number of samples with undetected concentrations. Although some changes in metals concentrations were observed after cooking, in general we found that cooking did not substantially alter the concentrations of metals in caribou bone or marrow, and that cooking these in soups with ingredients of varying acidity did not have any consistent effect on the resulting metals concentrations in the soups.

A conservative risk assessment was undertaken as part of the cooking study to evaluate the total metals intake from soups for a small child, which showed that risks from consumption of caribou in soup were lower than those calculated in the earlier risk assessments for meat, liver, and kidney. The results of this

study indicate that soups prepared with bone, meat, and marrow from caribou hunted in the vicinity of RDO are safe to eat and will not increase health risks due to potential increased consumption of lead, zinc or cadmium.

Introduction

Caribou are an integral part of life for Alaska Natives for both subsistence food and cultural importance (Magdanz et al. 2010, Garry et al. 2018). The Western Arctic Herd (WAH) is Alaska's largest caribou herd. The herd is distributed seasonally across over 360,000 km^2 of northwestern Alaska, across land that is under the management of many different landowners and agencies (Alaska Department of Fish and Game, ADFG 2020). Most of the WAH migrates in the fall across the Noatak and Kobuk Rivers to wintering grounds that include the upper Nulato Hills and the eastern Seward Peninsula (ADFG 2020). The WAH caribou typically travel from these wintering grounds over the Brooks Range, calve on the North Slope, and move towards the coast to escape insect harassment in mid-summer, then return south again in the fall (Baltensperger and Joly 2019). Oster et al. (2018) reported that female caribou in Alaska undergo the longest land migration of any ungulates, with females migrating 3000 km annually between their wintering grounds in the Brooks Range and calving grounds on the Coastal Plain.

WAH caribou, and also caribou from the Teshekpuk Lake Herd that can be sympatric (that is, overlapping in geographical distribution) with the WAH during winter (Joly and Cameron 2018), pass through and sometimes overwinter in areas that are naturally highly mineralized near Red Dog Operations (RDO). RDO, a zinc mine in northwest Alaska, is situated within one of the richest zinc deposits in the world (Garry et al. 2018). As forage quality in vascular plants decreases with the onset of fall, caribou primarily consume lichens. Lichens are a good source of energy and are understood to aid in caribou overwinter survival (Joly and Cameron 2018, Joly et al. 2015, Joly et al. 2007).

In the early 2000s, studies by National Park Service (NPS) scientists reported potential impacts to moss from metals in fugitive dust in the area surrounding RDO, which includes the mine, port site, and the DeLong Mountain Regional Transportation System (DMTS) road used to transport ore from the mine to the port site (Ford and Hasselbach 2001, Hasselbach et al. 2005). Based on these findings, the tundra surrounding RDO was studied extensively to characterize the nature and extent of metals from fugitive dust in mosses and lichens. In addition, potential exposures to metals through subsistence foods consumption were initially evaluated in 2001 by the Alaska Department of Public Health (ADPH 2001), and in a subsequent comprehensive human health risk assessment undertaken by Teck Alaska (Exponent 2007). The results of the ADPH study and the human health risk assessment showed that risks associated with subsistence consumption of caribou were estimated to fall within acceptable public health limits, indicating that caribou are safe for consumption. In addition, the study found that caribou harvested near the DMTS road have concentrations of metals in their tissues that are similar to concentrations detected in reference caribou harvested in other parts of Alaska and elsewhere in the world (Garry et al. 2018). Therefore, it was concluded that fugitive dust from RDO is not a significant source of metals (specifically lead, zinc, and cadmium) to caribou, and that caribou remained safe for consumption and changes to subsistence lifestyles were not necessary.

Protection of the environment, and caribou specifically as a cultural and subsistence resource, is of paramount importance for RDO. To monitor conditions going forward after completion of the risk assessment, a comprehensive RDO risk management process was undertaken jointly between Teck Alaska, the nearby communities, involved regulatory agencies, and other interested stakeholders. The RDO Fugitive Dust Risk Management Plan outlined seven fundamental risk management objectives that were agreed upon during the cooperative process. One of the objectives outlined is to "conduct research or studies to reduce uncertainties in the assessment of effects to humans and the environment" (Exponent 2014). Therefore, RDO's sustainability strategy includes implementation of research and studies that incorporate traditional knowledge, respond to community concerns, and address potential risks that were not assessed during the risk assessment process.

During meetings that were held as part of the risk management process, some community members expressed concerns that caribou bone and bone marrow, which are traditionally consumed in soups as part of the subsistence diet, were not evaluated in the DMTS risk assessment (Exponent 2007). In that assessment, metals concentrations measured in samples of muscle (meat), liver, and kidney were used to evaluate risks, because those items make up the majority of subsistence caribou consumption. Data were not collected for bone or bone marrow as part of the 2007 risk assessment.

To our knowledge, no other studies have determined whether metals are released from caribou bone (with meat and marrow) during cooking. When lead enters the body in mammals, it is distributed throughout the body via the bloodstream. Therefore, blood is typically monitored for lead exposure because it best reflects recent exposures (within approximately 30 days) (ATSDR 2019, Gordon et al. 2002, Lind et al. 2006, WHO 1995, WHO 2010, Wani et al. 2015). The bone structure (i.e., the solid portion of bone) on the other hand, is the primary long-term storage area for lead in mammals (Renner 2010, Silbergeld et al. 1993, Brito et al. 2000, Ufelle and Barchowsky 2019, ATSDR 2019, Gordon et al. 2002, Lind et al. 2006, WHO 1995, WHO 2010, Wani et al. 2015). Therefore, an evaluation of metals extracted from cooked caribou bone, with meat and marrow, was undertaken to address the community's concerns regarding potential release of metals from these food items during cooking.

The primary objective of this cooking study was to determine the amount of lead, cadmium, and zinc released from caribou bone, meat, and marrow into soup. Secondarily, we sought to determine if acidic ingredients commonly used to prepare caribou soup (such as vinegar or tomatoes) might alter the release of metals from meat, bone, and marrow. Third, resulting concentrations of metals in soup were compared to intake estimates from the risk assessment to determine if caribou prepared in soups is safe for human consumption. Finally, soups were prepared with alternative meats (commercially raised reindeer and beef) to determine if potential metals releases from the bone, marrow, and meat from these animals behaved in a manner similar to caribou.

Materials & Methods

Site Description

RDO is located at the western end of the Brooks Mountain Range, approximately 88 km inland from the Chukchi Sea. The study area is in northwest Alaska between the Delong Mountains and the Chukchi Sea (Figure 1). The mine has been in operation since 1989, mining and milling ore containing lead and zinc sulfides and producing zinc concentrate (55% zinc, 3.2% lead, and 0.33% cadmium) and lead concentrate (58% lead, 10.8% zinc, and 0.12% cadmium). The lead and zinc concentrates are transported year-round in trucks from the mine along the DMTS haul road, along an easement through the northern part of Cape Krusenstern National Monument, to the RDO port on the Chukchi Sea. Cape Krusenstern National Monument consists of a tundra ecosystem on the coastal plain, dominated by open, low, mixed shrub-sedge tussock tundra interspersed with low-lying, well-drained knolls that support a variety of lichen, forbs, and shrubs (Neitlich et al. 2017, Hasselbach et al. 2005). Soils within the Monument are poorly developed due to the cold climate, low precipitation, and the near-continuous permafrost (Hasselbach et al. 2005).

Caribou Harvest and Sampling

Caribou were collected near the DMTS road and in Cape Krusenstern National Monument on March 9, 10, and 12, 2018. Seven local subsistence hunters from the nearby communities of Kivalina and Noatak were selected to harvest the caribou by the Red Dog Mine Subsistence Committee, an advisory committee to RDO that shares traditional knowledge related to impacts on subsistence while practicing Iñupiaq ways of consensus, collaboration, and communication. The caribou were harvested using traditional knowledge and hunting methods and were shot in the head or cervical vertebrae whenever possible. Typically, caribou are shot and prepared in the field, but for this study, caribou were transported after harvest by snow machine to the RDO port site where a temporary laboratory was established at the Spill Prevention and Response Tent.

Twelve caribou were harvested near the DMTS road (hereafter referred to as Red Dog caribou) and eight caribou were harvested from the southern portion of Cape Krusenstern National Monument as a reference site (i.e., an area unaffected by metals from RDO). Figure 1 shows the harvest locations of the Red Dog caribou (locations 1-4) and the reference caribou (location 5). To evaluate the time caribou spent in the vicinity of RDO, the ADFG biologist used satellite-collar tracking data to determine that the caribou collected near the DMTS road (within 2.4 to 10.6 km) had likely stayed in the area for approximately three months prior to collection in March 2018. Based on the tracking data, it was determined that the reference caribou (collected approximately 57 km away from the DMTS road in Cape Krusenstern National Monument) had not passed through the RDO area or over the DMTS road during the three months prior to harvest. Note that satellite collar data were only used to estimate time spent in the area by caribou and were not used to direct hunters to harvest specific animals or to harvest animals from a particular location.

Harvested caribou were suspended from a pulley located inside the temporary laboratory and stored for necropsy (postmortem examination to evaluate internal structures) and sample collection. Prior to necropsy, surgical tools were cleaned with deionized (DI) water and Alconox® detergent to avoid cross-contamination between different caribou samples; disposable nitrile gloves were worn and changed at a minimum between each dissection and the laboratory work benches were lined with clean plastic. The caribou necropsies were conducted in collaboration with an ADFG wildlife biologist, a veterinarian from the Arctic University of Norway (University of Tromsø), and two veterinarians from the University of Anchorage, Fairbanks.

Caribou examinations and necropsies were used to document the overall health status of each animal, record health indices and characteristics, and to collect samples for additional research programs. Necropsies were conducted on the same day that the animals were harvested, usually within 1-4 hours of the time of death. For each caribou, the following information was recorded: harvest location, harvest date, sex, age estimate, pregnancy state, general health status, and gross pathology. Four leg shanks were collected from each caribou and randomly selected for the cooking study. "Shank" refers to the portion of the front legs with the radius and ulna, and the portion of the rear legs with the tibia and fibula (such as shown in this caribou skeletal anatomy illustration at http://www.ucalgary.ca/caribou/Skeleton.html).

Caribou leg, muscle (chest meat), kidney, and liver samples were collected, double-bagged, sealed, labeled, and stored in a freezer under appropriate chain-of-custody procedures. After tissue sample preparations, blood sample collection and health assessments were completed, and the remaining meat was packaged to send back to the local communities, ensuring no part of the caribou went to waste.

Commercial Reindeer and Beef Acquisition

Frozen reindeer and beef legs were purchased from a local meat supplier that provides meat to stores in villages in the Northwest Arctic Borough (NorthStar Quality Meats in Anchorage, Alaska). The frozen meat samples (i.e., leg shanks) were shipped on ice following appropriate chain-of-custody procedures to an accredited laboratory, ALS Environmental in Kelso, Washington, for analysis. Samples were continuously held in a freezer before study initiation. Sample details recorded for the reindeer and beef included the store location, brand, lot number, packaging material, date purchased, and expiration date.

Cooking Study

The cooking portion of the study was implemented in a controlled laboratory setting at ALS Environmental, using standardized cooking methods as described below.

Pre-Cooking Equipment Temperature Testing

Twenty-five identical slow cookers (Maxi-Matic Elite Gourmet 2-Quart Oval Slow Cooker, model MST-275XS) were used to cook the soups. Slow cookers were individually numbered, and the individual cooker used for each soup was identified on the lab bench sheet. Prior to use in the cooking study, slow cookers were pre-tested for six hours with water to verify their functionality and ability to maintain a consistent temperature range. Slow cooker temperatures were recorded after one and six hours in the pre-test. The temperature results averaged 68.9 degrees Celsius (range 65.3 to 74.6 ^{o}C) after one hour, and 95.7 ^{o}C (ranging from 87.9 to 99.6 ^{o}C) after six hours. Therefore, the cookers met the temperature requirements established in the study plan (within 20% of specified control limit) and were determined acceptable for use in the study.

Testing the Slow Cookers for Metals Leaching

A subset of the slow cookers used in the study was tested for potential metals leaching from the inner stoneware pot. Slow cooker blanks (referred to as pot blanks) were collected by adding DI water to the cooker and heating to the same temperature and duration as the final test soups. The lead and cadmium concentrations in water heated in the slow cookers were all below method reporting limits, and the maximum zinc concentration was 5.4 µg/L (Figure 2). Therefore, the slow cookers themselves were assumed to not contribute substantially to the metals concentrations measured in the final tests of cooked meat, marrow, bones, and soups.

Soup Recipes

Three soups were prepared for the study. One soup was water-based and the other two incorporated either tomato paste or vinegar, acidic ingredients hypothesized to mobilize or otherwise alter the release properties of metals from the meat, bone, and marrow (Table 1). The recipes used for the study were simple, and represent a range of acidity from neutral (water-based soup) to more acidic (tomato paste pH ranges from 3.5 to 4.7; vinegar pH ranges from 2.4 to 3.4) (Clemson University Extension, https://www.clemson.edu/extension/food/food2market/documents/ph_of_common_foods.pdf).

The amount of vinegar or tomato paste added to each soup was based on the results of testing the effects of common acidic ingredients within the range of proportions that are commonly used in beef bone broth recipes.

Table 1. Three soup recipes used in the study.

Water-Based Soup	Tomato-Based Soup	Vinegar-Based Soup
• 2-3-inch length of caribou, reindeer, or beef leg with meat and marrow intact • 40 ounces distilled water • 1 teaspoon salt	• 2-3-inch length of caribou, reindeer, or beef leg with meat and marrow intact • 40 ounces distilled water • 1 teaspoon tomato paste • 1 teaspoon salt	• 2-3-inch length of caribou, reindeer, or beef leg with meat and marrow intact • 40 ounces distilled water • 1 teaspoon distilled white vinegar • 1 teaspoon salt

Ingredient Testing

Ingredients collected for the cooking study were analyzed for metals prior to being used, to identify if individual ingredients might contribute to metals content in the cooked meat, bone, and marrow, and broths. Each ingredient was collected as a separate sample, then analyzed for concentrations of lead, cadmium, and zinc. Samples were tested for metals in triplicate for each of the ingredients. Soup ingredient brands were selected based on what was available at the Alaska Commercial Company grocery store in Kotzebue, Alaska (the largest community near the RDO). The following basic soup ingredients were tested: tomato paste, distilled white vinegar, non-iodized processed table salt, and distilled water. Lot numbers and brands for each of the ingredients used in the study were recorded.

Metals concentrations from raw soup ingredients (tomato paste, distilled white vinegar, non-iodized processed table salt, and distilled water) are shown in Table 2 and Figure 2. The raw soup ingredients were digested as neat materials and analyzed for the target metals, and reported on a liquid basis. Lead was detected only in salt at a maximum concentration of 0.11 µg/L. Cadmium and zinc were detected in tomato paste, with maximum concentrations of 0.362 µg/L and 28 µg/L, respectively, but were not detected in the other ingredients. No metals were detected in vinegar.

Slow Cooker Pot Controls

Pot control blanks were collected during the study to provide a measure of any metals concentrations the slow cooker stoneware pots, in combination with the soup ingredients, might have contributed to final soup ingredient samples. Pot controls were vegetarian versions of the soups, prepared by adding the ingredients used in each of the three soup recipes (i.e., DI water, salt, vinegar, and tomato paste) but without the addition of meat/bone/marrow. The vegetarian pot control soups were cooked for six hours, cooled, and collected in labeled sample containers. Metals were detected in the pot control soups at low concentrations with maximum concentrations of 0.19 µg/L for lead, 24.8 µg/L for zinc, and 0.29 µg/L for cadmium (Figure 2).

Meat, Bone, and Marrow Samples

The leg samples were processed at ALS Environmental, where the lab technician cut frozen caribou, reindeer, and beef legs into four pieces using a 22-inch butcher saw. Prior to cutting each leg, new disposable nitrile gloves were donned and the utensils and cutting boards were decontaminated by scrubbing with warm water and Alconox® until visually clean, rinsed with tap water, then triple rinsed with DI water.

Each leg sample was cut in into approximately four roughly equivalent pieces and thawed at room temperature (Figure 3). One of the four pieces from each leg was randomly selected and designated as the uncooked sample of meat, bone, or marrow. A clean, decontaminated knife was used to remove the thawed meat and marrow from the bone. The meat and marrow were weighed and then transferred to individual, labeled sample containers. The remaining bone, without meat or marrow, was rinsed with laboratory-grade DI water to remove any loose material, patted dry, and transferred to a labeled sample container. The other three pieces of bone/meat/marrow from each of the leg sections were left intact and used in the test soups.

A total of 105 uncooked meat, bone, and marrow samples, and another total of 420 cooked meat, bone and marrow samples were prepared and analyzed by ALS Environmental from nine Red Dog caribou, eight reference caribou, nine commercially available reindeer, and nine store-bought beef samples (Table 3).

Soup Preparation and Cooking

Each bone/meat/marrow piece (from Red Dog caribou, reference caribou, reindeer, or beef) was added to a slow cooker that contained all of the measured soup ingredients. Mass and/or volumes of each ingredient added to soups were recorded. Slow cookers and sampling and measuring devices were decontaminated prior to making each soup. The use of simple recipes (Table 1) allowed for preparation of 445 different soups and replicate samples for statistical comparisons (Table 3).

Soup, Meat, Marrow, and Bone Sampling

Each soup was cooked for six hours. Slow cooker temperatures were recorded after one and six hours; temperatures ranged from 87.9 to 99.6 ^{o}C. The soups were allowed to cool for one hour before sampling. When finished, each piece of bone (with meat and marrow) was carefully removed from the slow cooker and placed on a clean cutting board. The cooked meat and marrow were removed off each bone. A subsample of cooked meat and marrow was used for metals analyses, and the remainder of cooked meat and marrow was returned to the broth.

Metals Analyses

All samples were analyzed for three metals content (cadmium, lead, zinc). The laboratory processed each meat, bone, bone marrow, and broth sample before analysis by freeze drying each sample for 24 hours, followed by homogenization of the dried sample to a powder consistency. Each final dried sample was subsequently digested and analyzed for the target metals. Total metals were analyzed using the SW-846 Method 6020A, Inductively Coupled Plasma/Mass Spectrometry (ICP/MS) method, and total solids were analyzed using ALS Environmental's standard operating procedure (SOP) No. MET-TISP Revision 11 (2/23/2017) for Freeze-Dried Solids. The percent freeze-dried solid values were used to calculate sample wet-weight concentrations (since the metals analysis was performed on the dry-weight mass). Samples were analyzed in triplicate and were reported on both a wet-weight and dry-weight basis.

Quality Control Procedures and Data Quality Review

During the study, soups and subsequent samples were labeled with unique sample identifiers to maintain the identity of each sample throughout the process, from leg collection to bone cutting to soup preparation to data analysis. Also, to avoid contamination and cross-contamination, equipment used in the study (e.g., utensils, saw blades for cutting meat pieces, cutting boards, and slow cooker pots) was cleaned (decontaminated) with warm water and Alconox® detergent until visually clean, then rinsed with tap water, triple rinsed with DI water, and stored in a clean container for next use. Equipment rinsate blanks consisted of collecting DI water used to rinse soup-cooking equipment and were collected at a frequency of 1 per 20 samples processed.

Cooking study sample results and associated quality control (QC) sample results were reviewed by chemists using procedures consistent with U.S. EPA's National Functional Guidelines for data validation and method-specific requirements. Based on this review, 100% of the data were determined to be reliable and usable for evaluating potential risks associated with consumption of metals in caribou.

Statistical Analyses

Statistical analyses were conducted to evaluate differences between animal tissues from cooking, and from the type of soup stock. Where appropriate, analysis of variance (ANOVA) was used to evaluate overall differences followed by identification of specific differences using either Tukey's honest significant difference or t-tests for comparisons between only two groups. Differences at 95% confidence, or equivalently 0.05 significance, level were noted as statistically significant. Results qualified as not detected were included in the analyses at half the method reporting limit (MRL). Statistical comparisons for metals concentrations below the limit of detection for 50% or more of the samples were not considered reliable and were identified as such.

Results

As mentioned above, three types of soups (water-based, tomato-based, and vinegar-based) were prepared, ranging in acidity based on ingredients. Uncooked meat, bone, and marrow samples were compared to their cooked counterparts in soup. After the measured aliquots of bone, meat, and marrow were sampled, any leftover meat and marrow were returned to their respective cooked soup broths for sampling and analysis.

Prior to conducting the cooking study, the equipment and ingredients used in the study were tested for metals to determine if they may have contributed to the metals concentrations measured in cooked bone/meat/marrow and broth samples. Ingredient results are presented in Table 2 and Figure 2. Tomato paste showed higher cadmium and zinc concentrations than the other ingredients, and this was also noted in the pot control samples. Lead concentrations were highest in salt (Figure 2). Note that lead concentrations were highest for the tomato and vinegar "pot control" soups although concentrations were below the laboratory reporting limits for the individual tomato and vinegar ingredients. It is therefore possible that the acidic ingredients (tomato or vinegar) leached some lead from the slow cooker stoneware, but generally these concentrations were very low.

Table 4 presents results of the laboratory metals analyses of the meat/marrow/bone and broth samples and statistical differences between concentrations in the uncooked and cooked samples. Box plots illustrating the results and statistical differences are provided in Figure 4 for lead, Figure 5 for zinc, and Figure 6 for cadmium. Results are discussed in the sections below for caribou, reindeer, and beef.

Caribou Results

After cooking, there were no significant differences in lead concentrations between cooked and uncooked caribou meat, bone, and marrow, for caribou harvested from RDO or the reference area (Figure 4). Zinc concentrations in caribou marrow and bone also remained unchanged after cooking (Figure 5). However, zinc and cadmium concentrations increased significantly in meat after cooking, for both Red Dog and reference caribou (Table 4). Cadmium concentrations in marrow were generally unaffected by cooking, while concentrations in Red Dog caribou bones decreased after cooking, however more than half of cadmium concentration results were qualified as not detected, (Figure 6). There were no significant differences in lead or zinc concentrations between the different broths. Generally, cadmium concentrations were highest in tomato-based broths compared to vinegar- and water-based broths (Figure 6).

Reindeer Results

No significant changes in lead or cadmium concentrations occurred after cooking reindeer meat, bone, and marrow (Table 4), except for significantly lower lead concentrations in reindeer meat prepared in water-based soups as compared to tomato-based soups (Figure 4). This result may be unreliable because of the many results not detected. Zinc concentrations increased significantly after cooking reindeer meat, while zinc concentrations decreased significantly for reindeer marrow cooked in water-based soups (Figure 5). Zinc concentrations in reindeer bone were significantly lower when cooked in tomato-based soup than the other soup bases. Similarly, the tomato-based reindeer broth was significantly lower than the water- and vinegar-based broth (Table 4, Figure 5).

Beef Results

Similar to the results for reindeer and caribou, lead concentrations in beef meat, marrow, and bone were not affected by cooking (Figure 4). Zinc concentrations increased significantly in beef meat and marrow after cooking, while there was no change for bone (Figure 5). There were no significant differences in lead or zinc concentrations in beef broth, similar to what was found with caribou broth. Cadmium concentrations in beef meat and beef bone decreased after cooking in water-based soup, but not in the tomato or vinegar-based soups (Figure 6). Cadmium concentrations in beef marrow decreased after cooking in water, but marrow cooked in tomato- and vinegar-based soups showed higher concentrations. Because cadmium concentrations in all beef samples (meat, bone, marrow, and broth) were largely not detected, conclusions about concentration differences may be unreliable (Table 4). Statistical differences are largely affected by variability in the detection limits rather than meaningful differences in concentration between the sample types.

Discussion

The Importance of Traditional Knowledge

Comprehensive human health and ecological risk assessments were completed for RDO in 2007. The human health risk assessment (HHRA) concluded that subsistence foods, including caribou harvested from locations near RDO, were safe to eat and no changes were recommended to subsistence lifestyles for residents of local communities (Exponent 2007). In 2008, a 3-day “Risk Management Workshop” was convened in nearby Kotzebue, Alaska to present the results of the risk assessments and to identify priority research going forward. Workshop participants included community members and Elders from the nearby villages of Noatak and Kivalina, regulatory agency staff, and other interested stakeholders. Based on the input received during the workshop, a fugitive dust risk management plan (RMP) was drafted for RDO that considered all input from the workshop attendees. Six main objectives were developed for the RMP; three of the objectives related to human health risk management: 1) continue monitoring to verify the continued safety of caribou and other subsistence foods, 2) continue conducting studies to address uncertainties and data gaps in the risk assessment, and 3) continue communication and collaboration with all stakeholders.

The HHRA assessed consumption of caribou meat and organs as exposure pathways because caribou comprises a significant portion of the local diet. During the workshop, Kivalina and Noatak residents specified that they often cook caribou bones in soups, and also consume the meat, marrow, and broth. Therefore, the 2018 Caribou Cooking Study documented in this paper was planned to address this data gap, reduce uncertainties in the risk assessment, and verify the safety of caribou consumption when meat, marrow and bone are cooked in soups, thus achieving three of the ongoing objectives related to human health risk management.

Collaboration with and traditional knowledge of the local communities were incorporated throughout the cooking study, including identification of the caribou consumption issue at the Kotzebue workshop, study conception, planning, and design, conduct of the laboratory study, and final community presentations of the findings. Prior to the cooking study, the draft work plan was circulated to representatives from the organizations present at the Risk Management Workshop. The study design was modified to the extent feasible to incorporate input from the reviewers. For example, during the planning stages of the study, subsistence users advised that preparation of soup is the most common way to cook caribou, and all parts of the bone (meat and marrow intact) are used. Subsistence users also suggested that leg bones be used for the study because they are relatively large and have more marrow compared to other bones.

Additional input from the Red Dog Subsistence Committee was that the study be conducted during the fall migration period, the preferred time of year to hunt caribou. However, following discussion with members of the Committee, it was ultimately decided that it would be best to collect caribou in spring after they overwintered in the area to maximize the amount of time caribou spent near RDO. All caribou were harvested by subsistence hunters from Kivalina and Noatak. The hunters were not asked to harvest from specific sites, but instead to use their own traditional knowledge and to find caribou that were near RDO and others that were further away and could serve as reference caribou.

After the hunt, all caribou that was not used in the study was returned to the communities. Finally, at the onset of the cooking study, members from the Red Dog Subsistence Committee visited the ALS lab in Kelso, Washington, where the cooking study took place to discuss the study importance, and to offer their insights and suggestions regarding the proposed preparations for the meat and soups.

Cooking Effects on Bone and Marrow Concentrations

The potential effects of cooking on metals leaching were examined by comparing the uncooked meat, bone, and marrow to their cooked counterparts. We hypothesized that there would be a measurable difference in the metals concentrations between the uncooked bone and marrow and their cooked counterparts, assuming that metals would leach from the meat, marrow, and bones during cooking. Our results did not support this hypothesis; rather, in general we found that cooking did not substantially alter the concentrations in caribou bone or marrow for any of the metals tested (Table 4). The only change observed for caribou was that cadmium concentrations in bones from Red Dog caribou decreased when cooked in tomato-based broths (Figure 6). In contrast to caribou, reindeer and beef did not show similar patterns. There were some differences noted for zinc and cadmium concentrations in the bones and marrow of reindeer and beef before and after cooking, but results for cadmium are unreliable because of the large proportion of samples that had non-detected concentrations (Table 4, Figures 5 and 6). Overall, cooking did not appreciably affect metals concentrations in the bones and marrow of caribou, reindeer, or beef in any predictable or consistent manner.

There are no other known studies that report caribou bone or marrow metals concentrations before and after cooking for comparison in the scientific literature. Baxter et al. (1992) conducted a study using beef bones from cows that had consumed lead-contaminated feed. They prepared beef stock by boiling the bones along with water and vegetables for 5 hours, and did the same for "normal, uncontaminated" bones purchased from a local retail store. They analyzed the bones from cows that ate the lead-enriched feed and found that lead concentrations ranged from 4 to 25 mg/kg (wet weight) prior to boiling and 3.7 to 14 mg/kg after boiling (statistical significance was not mentioned). In the non-contaminated bones, the lead concentrations ranged from 0.3 to 1.1 mg/kg prior to cooking and 0.2 to 0.6 mg/kg after cooking. Consistent with the results from our cooking study, the lead content of the bones in the Baxter et al. (1992) study remained virtually unchanged by cooking, even for those bones with elevated lead concentrations.

Baxter et al. (1992) also evaluated lead leaching from bone under various cooking methods (i.e., boiled bones to create stocks and casseroles). They concluded that lead stored in bones did not transfer to food during cooking to any significant degree regardless of cooking method, even for the beef bones with elevated lead concentrations. This is consistent with our results for lead in beef, reindeer, and caribou bones, which did not change significantly after cooking.

There are many differences in the bone structure of animals that may prevent extrapolations between species used for cooking studies when evaluating metals releases, for example. Bone-tissue microstructure studies have been completed for different species to confirm or exclude the human origin of skeletal remains in forensic anthropology research. Martiniakova et al. (2006) stated that different species of mammals (humans, pigs, cows, sheep, rabbits, and rats) could be identified based on bone fragments by measuring the Haversian canals (the small tubes which form a network in bone and contain blood vessels) and osteons, which surround the Haversian canals. It is hypothesized that the Haversian canals may cause variations in the amounts of mineral extracted from bones across and within species. This was further explained by Hsu et al. (2017), who stated that these differences in bone-tissue microstructure among mammals make it difficult to make cross-species comparisons. In our study, the beef and the caribou bones were both tested, alleviating the need to infer that caribou and beef bones behaved similarly when cooked.

Cooking Effects on Meat Concentrations

The metal concentrations in caribou meat were hypothesized to leach into the broths and therefore, decrease in meat after cooking. Interestingly, and in contrast to our expectations, zinc and cadmium concentrations increased significantly in caribou meat after cooking, while lead concentrations showed no change (Table 4). Lead concentrations in reindeer and beef meat also did not change after cooking. However, zinc concentrations increased after cooking for all meats (caribou, reindeer, and beef) tested. There was no change in cadmium concentrations in the meat of reindeer or beef after cooking.

It is not understood why lead concentrations in the meat of caribou, reindeer, and beef were unaffected by cooking; this result was not expected. One explanation could be that the amount of lead remained the same, but cooking altered the meat in a way that decreased the moisture content, resulting in increased lead concentrations. However, analysis of dry-weight concentrations does not support this hypothesis; dry-weight concentrations generally showed the same differences as wet-weight concentrations. Furthermore, this would not explain the discordant results between metals, with lead concentrations in meat being unaffected by cooking, but zinc and cadmium concentrations significantly changed (Table 4).

The results from other peer-reviewed studies did not help elucidate why in our study cadmium and zinc concentrations, but not lead, may have increased in meat after cooking. Joyce et al. (2016) studied the effects of different cooking methods on metals in game meat (cane rat and Giant rat) in Ghana. In contrast to our study, they found that lead concentrations increased in meat after boiling, from 4.3 mg/kg to 13.7 mg/kg. Also in contrast to the results from our study, they reported similar cadmium and zinc concentrations before and after cooking. An alternative explanation for the differences between metals concentrations after cooking is that meat preferentially absorbed zinc and cadmium (but not lead) from the broth, but the mechanism for this differential uptake is unclear. It remains unknown why the cadmium and zinc concentrations (but not lead) in meat increased after cooking in our study.

Metals contributions from the slow cookers in leach testing were very low, as were concentrations in the additional ingredients used in the recipes (i.e., salt, vinegar, tomato paste; see Table 2 and Figure 2), ruling out the possibility that zinc and cadmium were present in elevated amounts in the equipment or other ingredients used to cook the soups. This is further supported by the low metals concentrations detected in the pot control samples (broths made without the addition of bone, meat and marrow; Figure 2).

Effects of Cooking with Acidic Ingredients

In this study, three types of soups were prepared to reflect different acidity levels that might influence the leaching of metals from bone, meat, and marrow into the broths: water-based, tomato-based, and vinegar-based. If acidic ingredients used during cooking have an influence on metal leaching from bone, meat, or marrow into the broth, we expected metal concentrations to be lowest in water-based broths, followed by the tomato-based broths, and highest in the vinegar-based broths since vinegar has the highest acidity. In contrast to what was expected, our study results showed no difference in metals concentrations between broth recipe types prepared with caribou meat, marrow, and bone (Table 4).

The soups prepared with commercially available reindeer and beef also showed results in contrast to expectations. For example, tomato-based broths made with reindeer meat, marrow, and bone had significantly lower zinc concentrations than the water- and vinegar-based broths (Figure 5). The only preparation that followed the expected trend was cadmium concentrations in the soup prepared with beef, where the water-based broths had significantly lower concentrations than the vinegar- and tomato-based broths (Figure 6). Overall, cooking meat, marrow and bone in soups with ingredients of varying acidity did not have a clear or consistent effect on metals concentrations in broths except lead. Our study results showed generally consistent lead concentrations for all three broth types, indicating no change based on the acidity of ingredients. (Figure 4).

Vegetarian versions of the caribou, beef, and reindeer soups (pot controls) were prepared to test whether the soup ingredients may have affected metals concentrations. Results for these samples are shown in Figure 2. It was noted earlier that the acidic ingredients (tomato and vinegar) may have leached some lead from the slow cooker stoneware in the pot controls, but lead concentrations did not increase in meat after cooking, suggesting that any leaching from the pots themselves was minimal. The highest concentrations of zinc and cadmium were found in tomato paste, compared to water, vinegar and salt. However, the pot controls (vegetarian soup) samples had lower concentrations than what was present in tomato paste as a raw uncooked ingredient, suggesting that leaching of metals from the pots did not occur, but instead potentially small amounts of cadmium and zinc may have been taken up by meat due to tomatoes. However, the results were not consistent among tests (that is, tomato-based broths did not consistently show the highest concentrations of zinc or cadmium), so this is not likely the explanation for increased zinc and cadmium concentrations in meat after cooking.

Few previous studies have examined the effect of acidic ingredients on the leaching of metals from bones in cooked foods. In one part of their multi-part study, Baxter et al. (1992) prepared casseroles by marinating both lead-contaminated and uncontaminated beef bones in red wine for several hours prior to cooking. The authors suggested some leaching of lead did occur when beef bones were cooked in red wine for casseroles, but lead levels were described as “on average less than double found in casseroles prepared with uncontaminated bones.” Baxter et al. (1992) concluded that lead does not considerably leach from heavily contaminated beef bones, which agrees with our own findings.

Hsu et al. (2017) prepared an acidified bone broth using white pig bones. They mixed 20 ml of table vinegar with 1 liter of deionized water; for comparison, our study used 14 ml of table vinegar or 14 ml of tomato paste with 1 liter of distilled water. When the bones started boiling, Hsu et al. (2017) reduced the broths to a simmer at 95-100 degrees Celsius, similar to the temperatures used in our study, which averaged 97.9 degrees Celsius. Consistent with the results from our study, Hsu et al. (2017) found no significant differences between zinc and lead concentrations in broths prepared with pig bones cooked in acidified versus unacidified water, but other minerals (calcium and magnesium) did show significant increases when cooked with water acidified with vinegar.

Hsu et al. (2017) also analyzed three “commercial” broths prepared with beef and either noodles or herbs, and then sampled the broth. The maximum lead, zinc, and cadmium concentrations in broth were reported as 0.0090 mg/kg, 0.68 mg/kg, and 0.0016 mg/kg, respectively. The commercially available broths contained lead and cadmium at concentrations that were higher than what was measured in our beef broths; where maximum lead and cadmium concentrations were 0.00077 mg/kg and 0.00041 mg/kg, respectively (Figures 4 and 6); maximum zinc concentrations were an order of magnitude higher in broths prepared with beef at 6.28 mg/kg (Figure 5) compared to 0.68 mg/kg measured by Hsu et al. (2017). However, results between the Hsu et al. (2017) study and our own study are not truly comparable. One major difference is that Hsu et al. (2017) removed as much fat and residue from the bones used in their study prior to cooking, whereas we left bone pieces with meat and marrow intact. Also, after collecting samples of bone, meat, and marrow for separate analysis, we added all remaining meat and marrow back into the broth before the broth was sampled to simulate what subsistence users would consume.

Health Assessment for Consuming Soup Cooked with Caribou Meat, Bone and Marrow

The comprehensive HHRA completed for RDO in 2007 addressed exposure to metals from multiple pathways, including incidental ingestion of dust, soil, and water, and consumption of subsistence foods (Garry et al. 2020). The risk assessment found that the estimated intake of metals from Red Dog fugitive dust was within acceptable limits, and concluded that subsistence foods, including caribou, were safe to continue eating. As previously described, the risk assessment evaluated metals intake from caribou meat, liver, and kidney, but did not include the potential contribution from bone and bone marrow. The present study addresses this data gap by estimating the transfer of metals from caribou bone to soup in addition to the contribution from marrow and meat.

To assess the possible intake of metals from the soups in our study relative to the intake from consuming caribou meat, liver, and kidney as estimated in the risk assessment, we calculated total metals intake from the soups for a small child. The conservative risk assessment estimated a higher metals intake per unit body weight for children (0 to 6 years of age) than for adults. Our inputs for these calculations were based on the highest mean concentrations of each metal from any of the soup recipes made with Red Dog caribou bone, marrow, and meat; from the tomato-based soup for lead and cadmium and the vinegar-based soup for zinc.

Although standard serving sizes are available for soups for the general population, they may not be representative of typical serving sizes for Iñupiat people within the region and are particularly not relevant as an estimate of a full meal for a small child. In the study discussed above, Hsu et al. (2017) calculated the intake of metals from bone broths assuming a 0.5 liter serving per day, a portion that would likely exceed the daily intake for a child less than seven years of age. Nevertheless, assuming the highest mean concentrations and a daily consumption rate of 0.5 L/day along with the other exposure assumptions used in the risk assessment, the daily intake from soup prepared with caribou bones (including marrow and meat) for small children was estimated to be 0.03 µg/day for cadmium , 0.4 µg/day for lead, and 123 µg/day for zinc. For comparison, the estimated intake from caribou meat, liver, and kidney in the earlier HHRA, though determined to be safe, was much higher than from soups in this study: 1.5 µg/day for cadmium, 1.7 µg/day for lead, and 285 µg/day for zinc (Exponent 2007). Therefore, if caribou consumption from soup replaced the intake from meat and organs evaluated in the risk assessment, estimated risks would be lower than calculated in the risk assessment.

The results of this study indicate that soups prepared by subsistence users with bone, meat, and marrow from caribou hunted in the vicinity of RDO are safe to eat and will not increase health risk. During the winter, caribou are known to primarily consume lichens because they are a rich source of energy (Joly and Cameron 2018, Joly et al. 2015, Joly et al. 2007). Lichens are considered particularly effective at absorbing airborne nutrients as well as contaminants such as metals (Gamberg et al. 2016). Therefore, utilizing the caribou in our study that overwintered near RDO while they primarily consumed lichens (i.e., maximizing potential exposure) provides a conservative estimate of risk.

Importance of Traditional Subsistence Foods

It is expensive to have meat such as beef shipped to the Arctic, therefore caribou serves as a valuable resource for residents in the Northwest Arctic. Continued consumption of traditional subsistence food diets promotes multiple health benefits over those that emphasize Western foods. For example, caribou is considered a top dietary source of iron and several micronutrients necessary for red blood cell production in the contemporary diet of Inuit adults across Canada (Kenny et al. 2018). Additionally, Bersamin et al. (2008) studied diet differences among Yup'ik peoples in remote communities of Alaska and reported that diets emphasizing traditional Alaskan Native foods were associated with a fatty acid profile promoting greater cardiovascular health than diets emphasizing Western foods. Specifically, study participants that consumed traditional subsistence foods had significantly lower serum triglyceride concentrations and higher high-density lipoproteins (HDL, the "good" cholesterol), both of which have been found to decrease the risk of chronic disease (Bersamin et al. 2008).

There is a growing body of research that suggests meat obtained from animals in their natural habitats, as opposed to being kept in enclosures, is associated with multiple health benefits (Haskins et al. 2019, Pham et al. 2019, Valencak and Gamsjager 2014, Daley et al. 2010, Van Elswyk et al. 2014). Some researchers report that wild or free-range animals have fewer calories, higher mineral and protein content, higher antioxidant content, and significantly higher amounts of nutrients that may protect against cancer, such as omega-3 fatty and enhanced total conjugated linoleic acids, plus higher percentages of polyunsaturated fatty acids than their farmed counterparts (Tidball et al. 2014, Valencak and Gamsjager 2014, Elswyk et al. 2014, and Daley et al. 2010). Recently, it was reported that moose and caribou meat both contain not only vitamins, but also monoacetyldiglycerides, diglycerides, and fatty acid ester of hydroxyl fatty acids, considered new classes of recently discovered functional lipids that have potential therapeutic significance in the management and prevention of metabolic or inflammatory diseases including obesity, type 2 diabetes, sepsis, and rheumatoid arthritis (Pham et al. 2019, Hassan et al. 2012).

The locomotion involved with free-range rearing has been credited for the development of a healthy muscle fatty acid composition in wild game (Valencak and Gamsjager 2014). Superior fatty acid profiles in wild game meat are also attributed to the forage consumed as part of the animals' natural diet (Pham et al. 2019). Additionally, Provenza et al. (2019) suggested that human health is enhanced when livestock forage on phytochemically rich landscapes that include mixtures of grasses, forbs, shrubs, and trees, possibly because the phytochemicals in herbivore diets protect meat and dairy from oxidation and lipid peroxidation that cause low grade system inflammation that has been implicated in heart disease and cancer in humans. The importance of plant diversity in forage has been noted by Joly and Cameron (2018) for large herds of migratory caribou in northwest Alaska, where lichens composed 71% of late winter and early fall diets, and moss (11%) and shrubs (9%) were the next most common dietary components. Furthermore, animals that forage on diverse pastures as opposed to being raised on feed lots are not administered feed additives for growth promotion, nor prophylactic antibiotics for disease prevention, which has been attributed to issues such as worldwide antimicrobial resistance (Silbergeld et al. 2008). It is for these reasons that big game cervids such as moose and caribou are gaining popularity as excellent sources of meat with superior fatty acid profiles when compared to traditional farm-raised animals (Pham et al. 2019), and that traditional subsistence foods such as caribou remain vital to the health and wellness of Arctic Indigenous Peoples (Kenny et al. 2019).

Risk Management Program

RDO is located in an area enriched with naturally occurring metals (O'Hara et al. 2003). In addition, atmospheric transport and deposition contributes pollutants, including lead and cadmium, to the region (AMAP 2005, 2009, 2011). One of the six objectives of the RDO RMP is to continue reducing fugitive dust emissions to protect human health and the environment. Therefore, risk management at RDO focuses not only on monitoring caribou and other important resources, but also on continually reducing metals concentrations from fugitive dust over the life of the mine. Large investments in the improvement of infrastructure and ongoing use of best management practices to limit the transport of fugitive dust have resulted in reductions in metals deposition to the environment surrounding RDO (Neitlich et al. 2017). Improvements and best management practices continue today, and are planned to continue for the life of the mine as well as after closure.

Conclusions

This study was specifically designed to answer questions that are relevant for subsistence users about the safety of consuming soups prepared with bones, meat, and marrow from caribou collected in the vicinity of RDO. Metals from meat, bone, and marrow did not appear to be substantially leached out into the broths during cooking. Cooking with acidic ingredients did not have the expected effect of increasing metals concentrations in broth. Although zinc and cadmium concentrations were found to increase in caribou meat after cooking, the estimated risks from consumption of caribou soups were lower than those calculated for consumption of caribou meat and organs in the 2007 HHRA, which were concluded to be within acceptable limits. The results of this cooking study therefore reconfirmed that caribou harvested in the area of RDO remain safe for consumption, either raw or cooked in soups.

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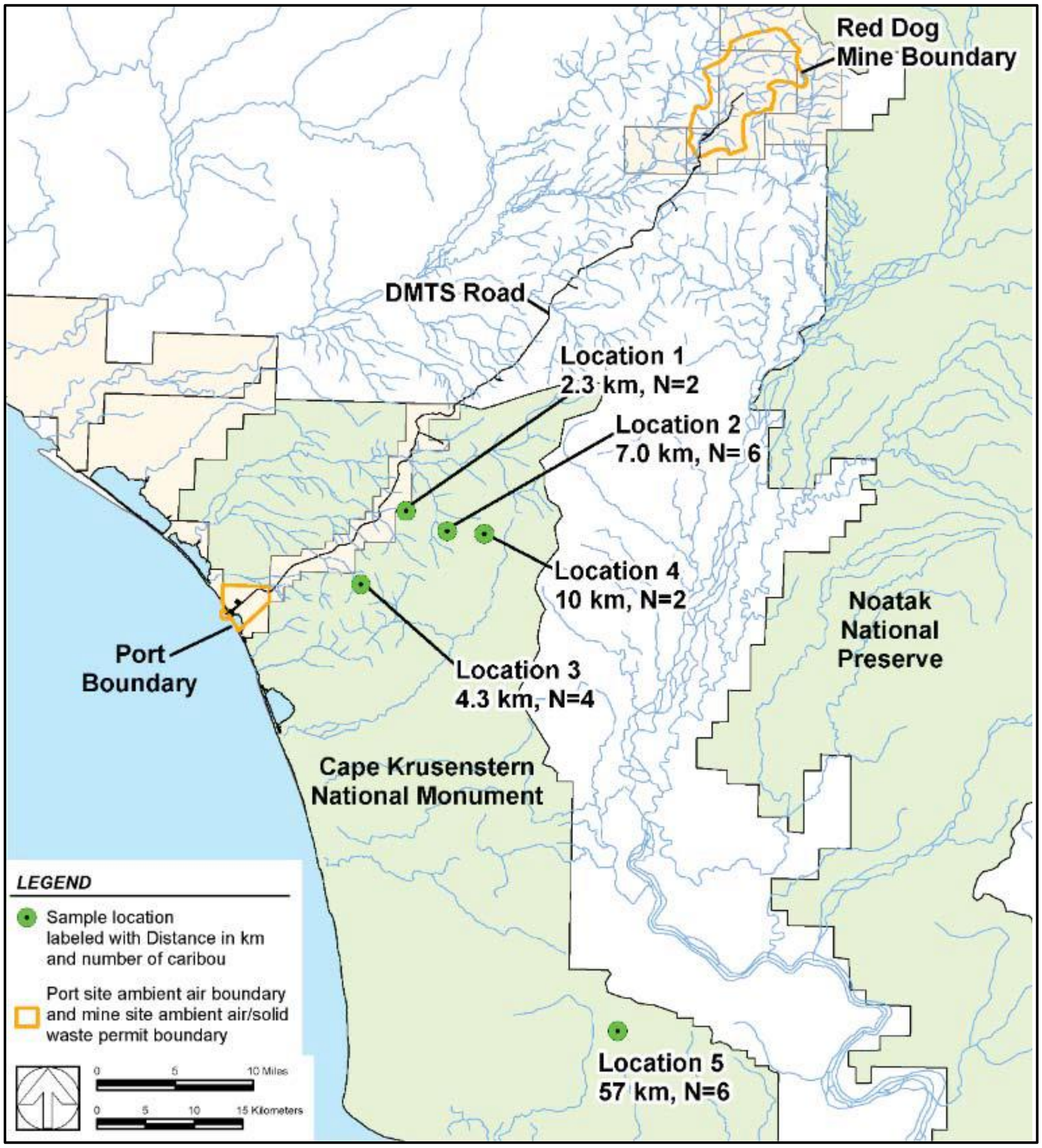
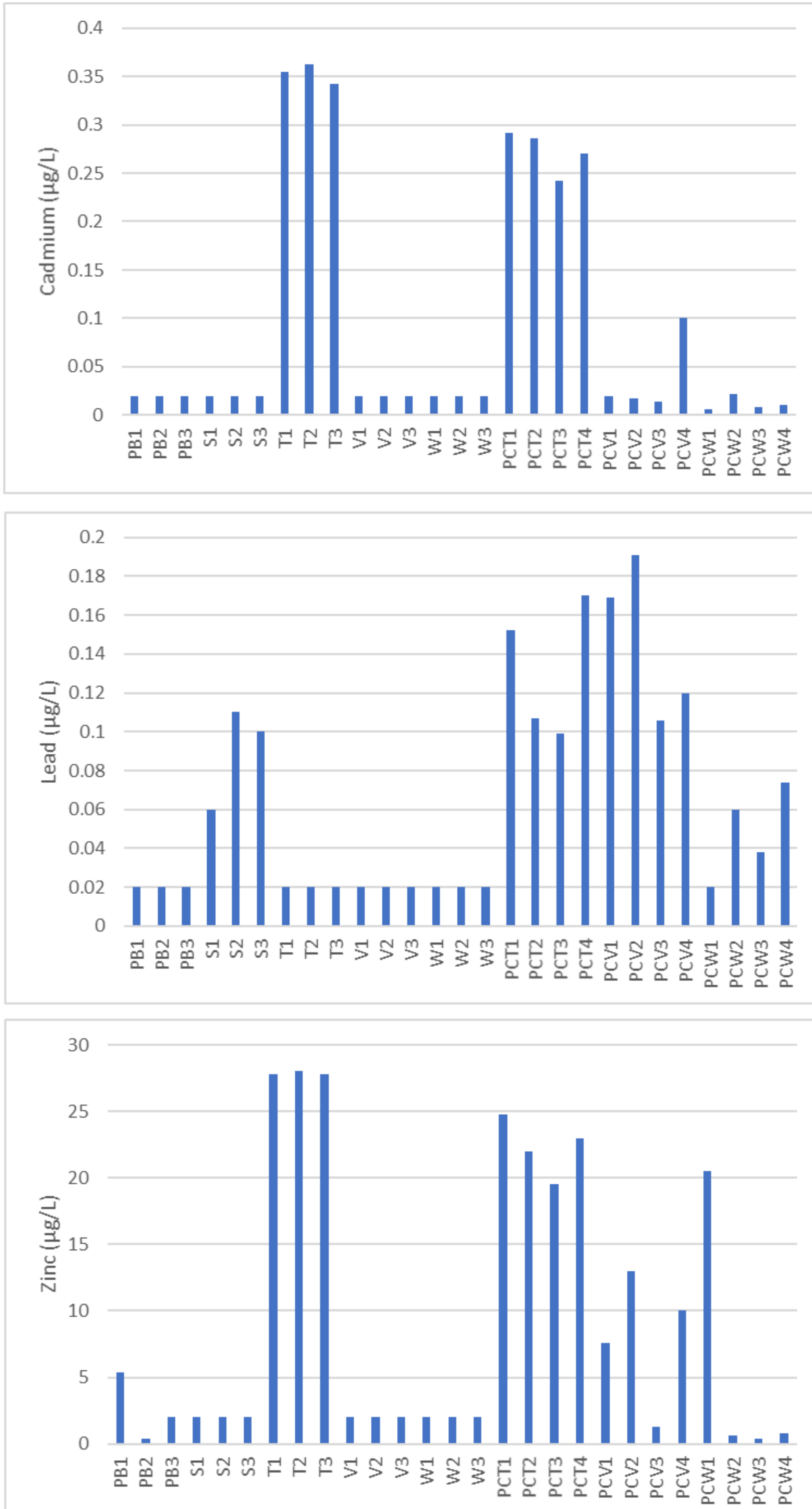


Figure 1. Caribou harvest locations for cooking study



PB: Pot Blank
S: Salt
T: Tomato Paste
V: Vinegar
W: DI Water
PCT: Pot Control, Tomato-Base
PCV: Pot Control, Vinegar-Base
PCW: Pot Control, Water-Base
MRL: Method Reporting Limit

Pot Blank: Pot + DI Water
Pot Control: Pot + Soup Base

MRLs:
Cadmium: 0.02 ug/L
Lead: 0.02 ug/L
Zinc: 2.0 ug/L

Figure 2. Equipment and ingredient testing for metals

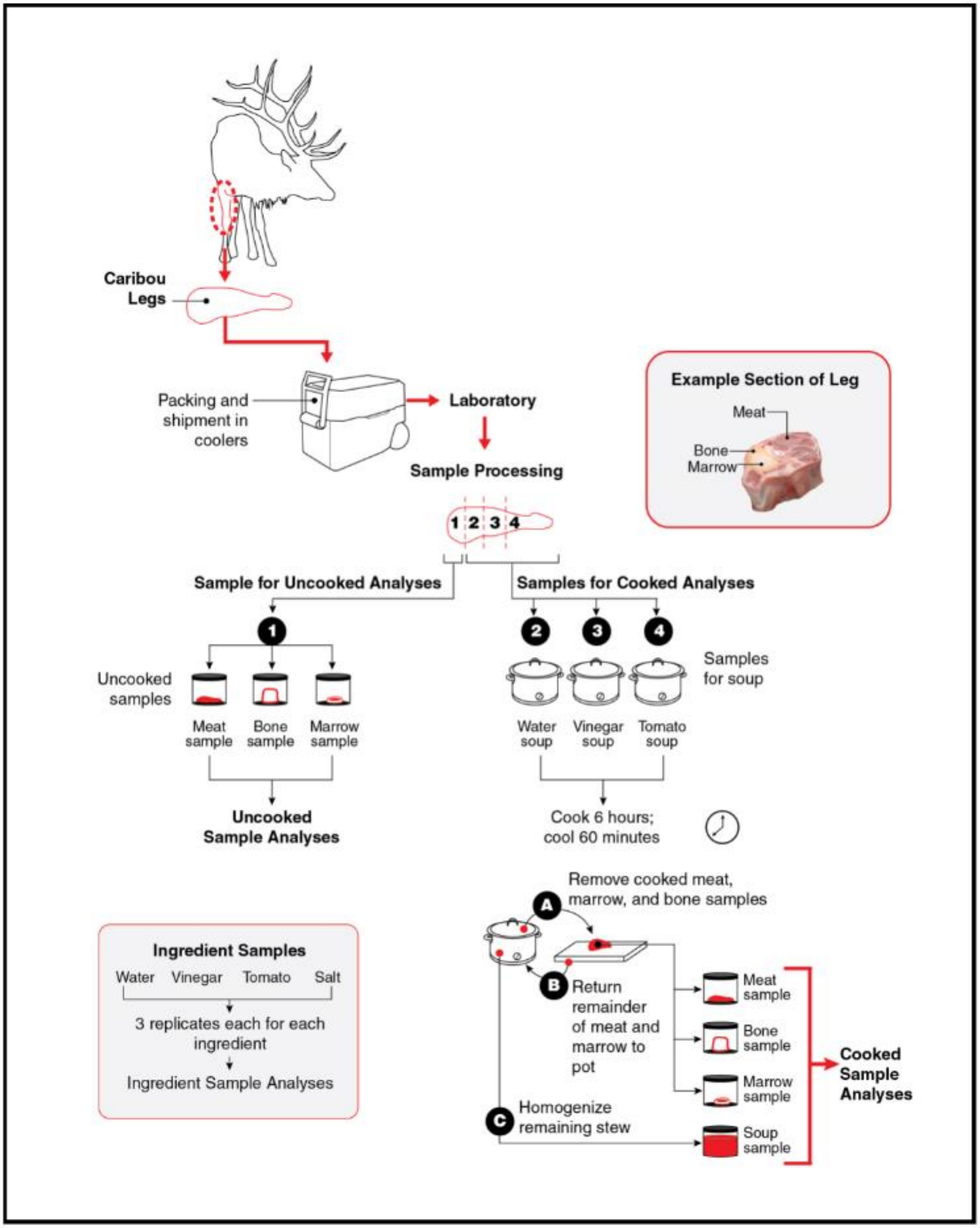


Figure 3. Caribou cooking study sample preparation and processing

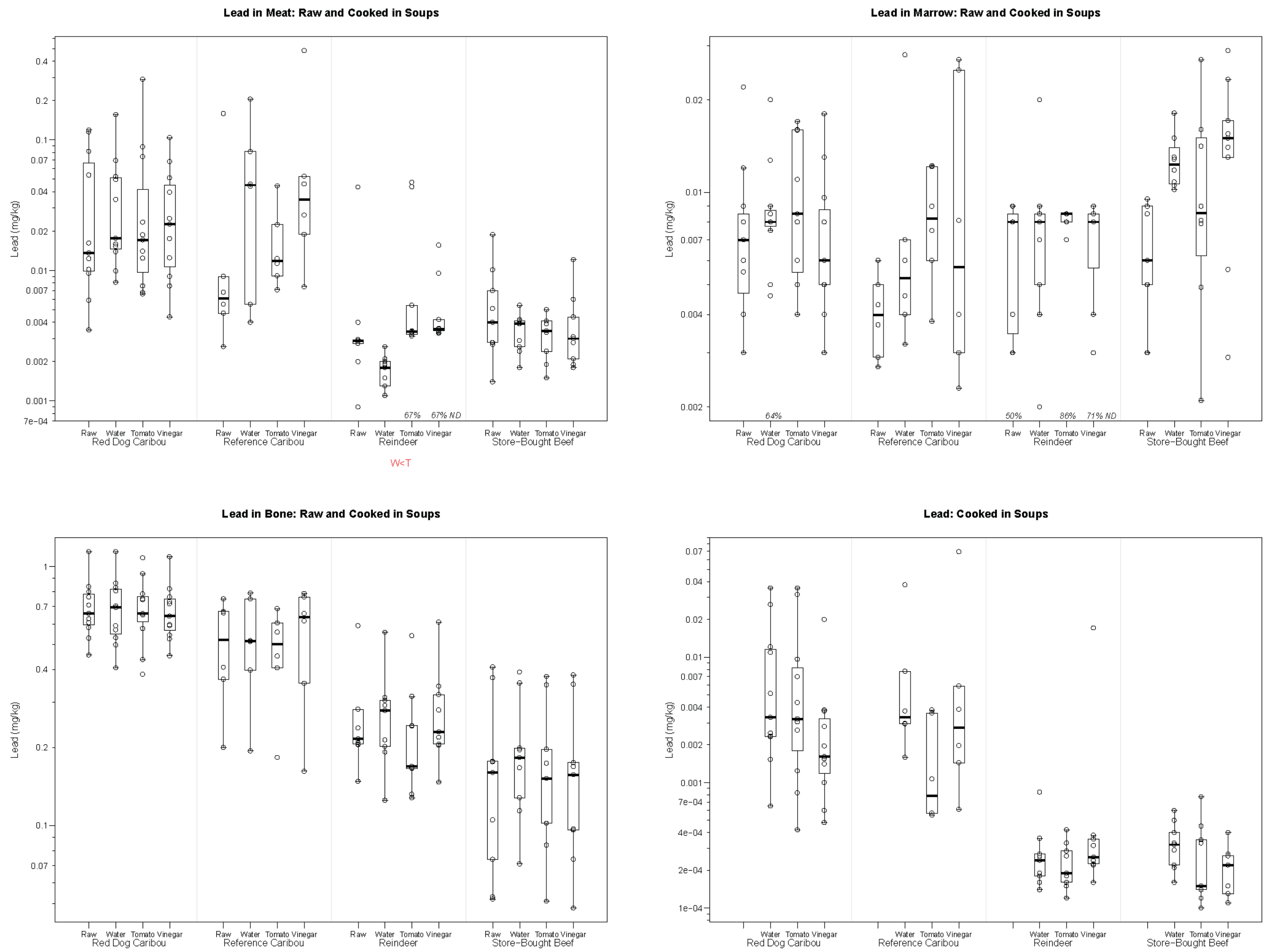


Figure 4. Comparison of raw and cooked samples for lead

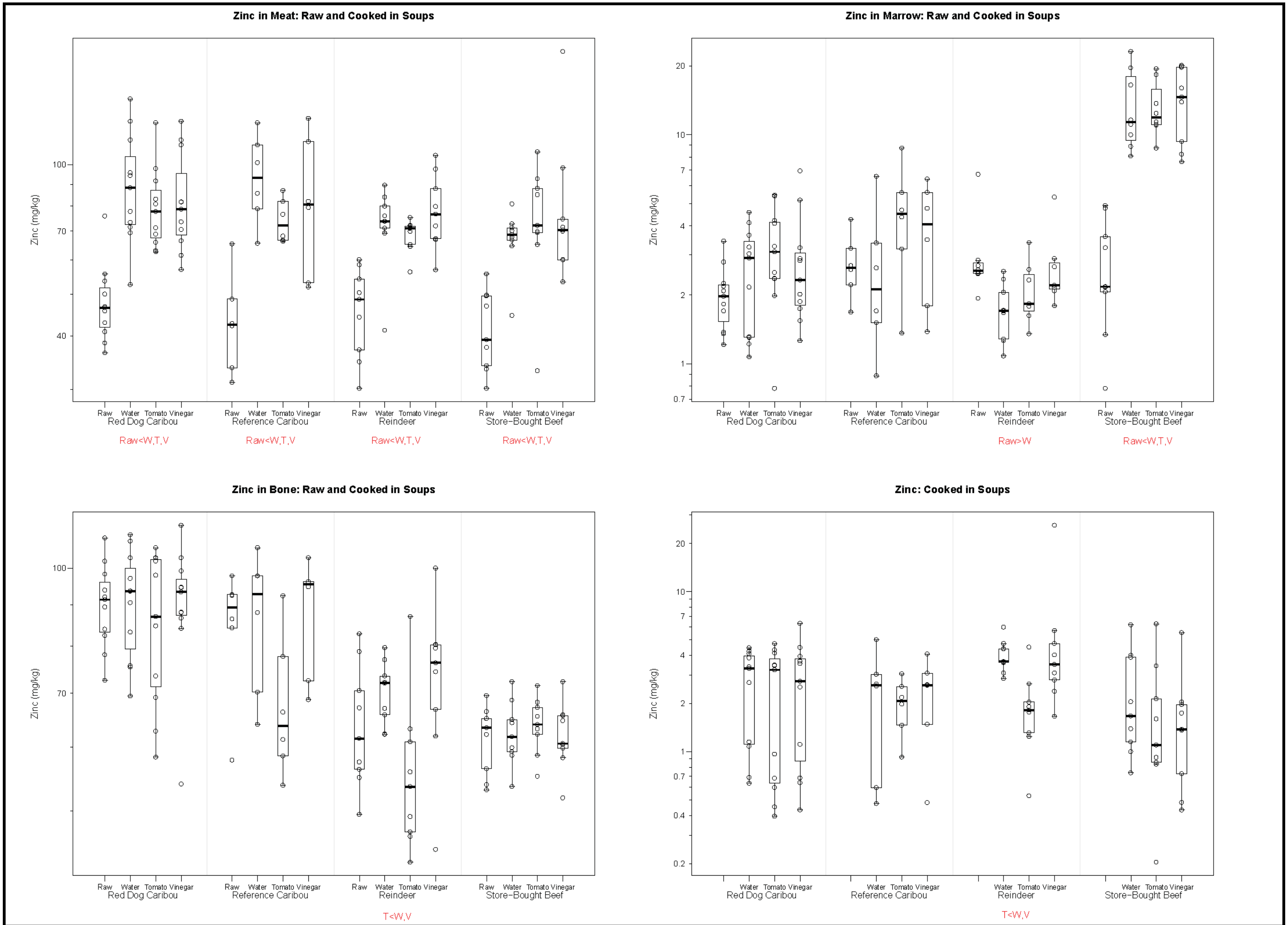


Figure 5. Comparison of raw and cooked samples for zinc

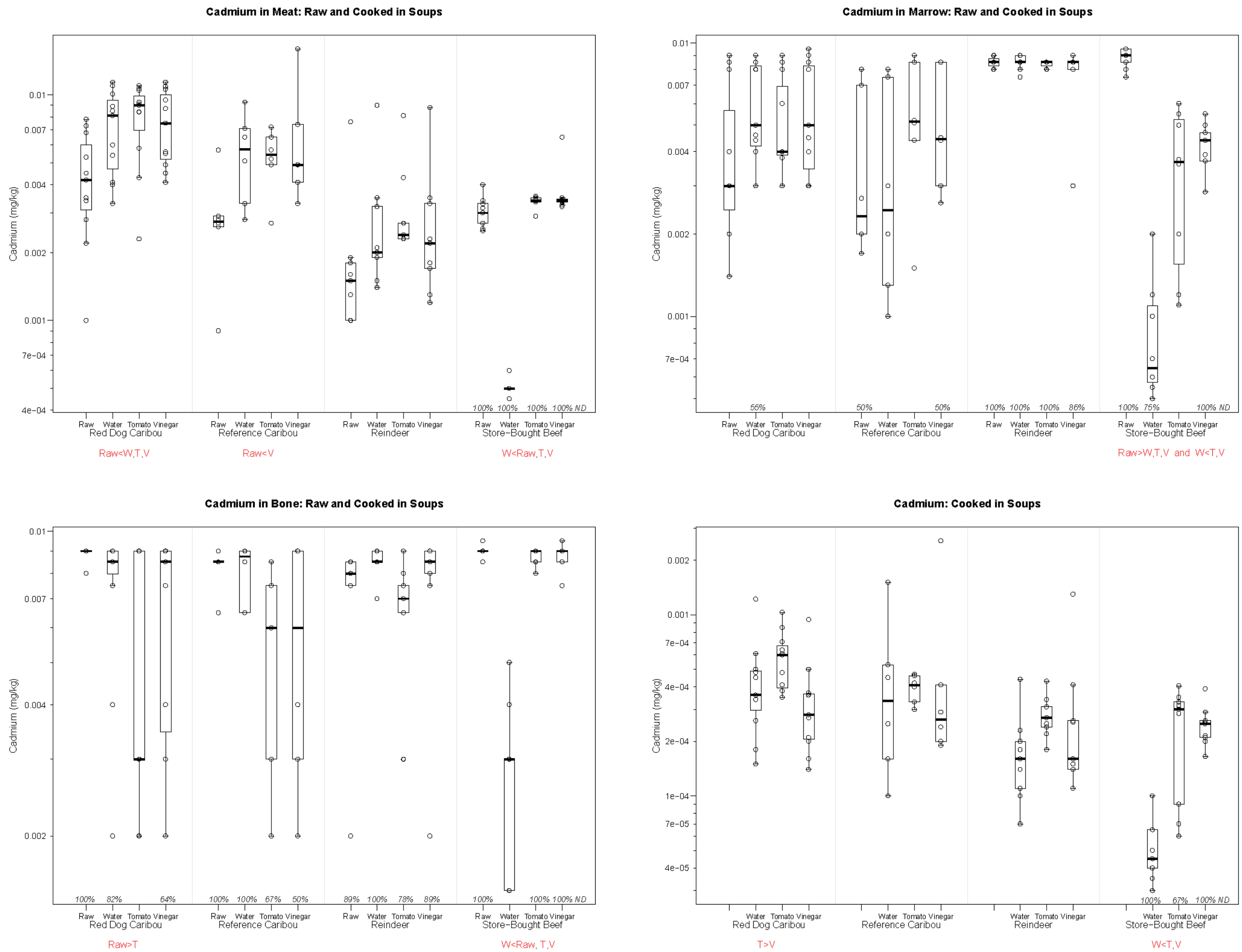


Figure 6. Comparison of raw and cooked samples for cadmium

Table 2. Summary of anaytical results for pre-cooking ingredients

Sample ID	Sample Type	Analyte	Units	Final Validated Result	
S1	Salt	Cadmium	ug/L	0.02	U
S1	Salt	Lead	ug/L	0.06	J
S1	Salt	Zinc	ug/L	2	U
S2	Salt	Cadmium	ug/L	0.02	U
S2	Salt	Lead	ug/L	0.11	
S2	Salt	Zinc	ug/L	2	U
S3	Salt	Cadmium	ug/L	0.02	U
S3	Salt	Lead	ug/L	0.1	
S3	Salt	Zinc	ug/L	2	U
T1	Tomato	Cadmium	ug/L	0.355	
T1	Tomato	Lead	ug/L	0.02	U
T1	Tomato	Zinc	ug/L	27.8	
T2	Tomato	Cadmium	ug/L	0.362	
T2	Tomato	Lead	ug/L	0.02	U
T2	Tomato	Zinc	ug/L	28	
T3	Tomato	Cadmium	ug/L	0.342	
T3	Tomato	Lead	ug/L	0.02	U
T3	Tomato	Zinc	ug/L	27.8	
V1	Vinegar	Cadmium	ug/L	0.02	U
V1	Vinegar	Lead	ug/L	0.02	U
V1	Vinegar	Zinc	ug/L	2	U
V2	Vinegar	Cadmium	ug/L	0.02	U
V2	Vinegar	Lead	ug/L	0.02	U
V2	Vinegar	Zinc	ug/L	2	U
V3	Vinegar	Cadmium	ug/L	0.02	U
V3	Vinegar	Lead	ug/L	0.02	U
V3	Vinegar	Zinc	ug/L	2	U
W1	DI Water	Cadmium	ug/L	0.02	U
W1	DI Water	Lead	ug/L	0.02	U
W1	DI Water	Zinc	ug/L	2	U
W2	DI Water	Cadmium	ug/L	0.02	U
W2	DI Water	Lead	ug/L	0.02	U
W2	DI Water	Zinc	ug/L	2	U
W3	DI Water	Cadmium	ug/L	0.02	U
W3	DI Water	Lead	ug/L	0.02	U
W3	DI Water	Zinc	ug/L	2	U

Notes:

J: Estimated result

U: Undected

Anaytical method 6020A

Table 3. Caribou cooking study sample matrix

Pre-Cooking	Metals Analysis of Ingredients and Cooking Equipment					Equipment Rinsate Blanks		
Sample Type:	Slow Cooker Blanks	Distilled Water	Vinegar	Tomato	Salt	Saw Blade	Measuring Cup	Ladle
	PT1-B	W1	V1	T1	S1	SB-1	MC-1	L-1
	PT2-B	W2	V2	T2	S2	SB-2	MC-2	L-2
	PT3-B	W3	V3	T3	S3	SB-3	MC-3	L-3

Color coding key:

Yellow	Sample was not analyzed or reported. For marrow samples, insufficient sample marrow to perform analysis.
Peach	Additional sample reported by laboratory; not part of original sample plan.

Shank Numbering (Cut for Samples)	Pre-Cooking Study Uncooked Ingredient Samples			Cooked Samples from Soups												Sample Counts			
				Water-Based Soup				Vinegar-Based Soup				Tomato-Based Soup							
	Meat	Bone	Marrow	Meat	Bone	Marrow	Soup	Meat	Bone	Marrow	Soup	Meat	Bone	Marrow	Soup	Uncooked Meat, Bone, and Marrow	Cooked Meat, Bone, Marrow, and Soup	Total Equipment Blanks	Total Pot Control Blanks
Store-bought Beef																			
BE1	BE1-MT	BE1-BN	BE1-MA	BE1-WMT	BE1-WBN	BE1-WMA	BE1-WST	BE1-VMT	BE1-VBN	BE1-VMA	BE1-VST	BE1-TMT	BE1-TBN	BE1-TMA	BE1-TST	3	12		
BE2	BE2-MT	BE2-BN	BE2-MA	BE2-WMT	BE2-WBN	BE2-WMA	BE2-WST	BE2-VMT	BE2-VBN	BE2-VMA	BE2-VST	BE2-TMT	BE2-TBN	BE2-TMA	BE2-TST	3	12		
BE3	BE3-MT	BE3-BN	BE3-MA	BE3-WMT	BE3-WBN	BE3-WMA	BE3-WST	BE3-VMT	BE3-VBN	BE3-VMA	BE3-VST	BE3-TMT	BE3-TBN	BE3-TMA	BE3-TST	3	12		
BE4	BE4-MT	BE4-BN	BE4-MA	BE4-WMT	BE4-WBN	BE4-WMA	BE4-WST	BE4-VMT	BE4-VBN	BE4-VMA	BE4-VST	BE4-TMT	BE4-TBN	BE4-TMA	BE4-TST	3	12		
BE5	BE5-MT	BE5-BN	BE5-MA	BE5-WMT	BE5-WBN	BE5-WMA	BE5-WST	BE5-VMT	BE5-VBN	BE5-VMA	BE5-VST	BE5-TMT	BE5-TBN	BE5-TMA	BE5-TST	3	12		
BE6	BE6-MT	BE6-BN	BE6-MA	BE6-WMT	BE6-WBN	BE6-WMA	BE6-WST	BE6-VMT	BE6-VBN	BE6-VMA	BE6-VST	BE6-TMT	BE6-TBN	BE6-TMA	BE6-TST	3	12		
BE7	BE7-MT	BE7-BN	BE7-MA	BE7-WMT	BE7-WBN	BE7-WMA	BE7-WST	BE7-VMT	BE7-VBN	BE7-VMA	BE7-VST	BE7-TMT	BE7-TBN	BE7-TMA	BE7-TST	3	12		
BE8	BE8-MT	BE8-BN	BE8-MA	BE8-WMT	BE8-WBN	BE8-WMA	BE8-WST	BE8-VMT	BE8-VBN	BE8-VMA	BE8-VST	BE8-TMT	BE8-TBN	BE8-TMA	BE8-TST	3	12		
BE9	BE9-MT	BE9-BN	BE9-MA	BE9-WMT	BE9-WBN	BE9-WMA	BE9-WST	BE9-VMT	BE9-VBN	BE9-VMA	BE9-VST	BE9-TMT	BE9-TBN	BE9-TMA	BE9-TST	3	12		
	EB1-U			EB1-W		PT0-W	PT1-W	EB2-V			PT2-V	EB3-T			PT3-T			3	4
Reindeer																			
RE1	RE1-MT	RE1-BN	RE1-MA	RE1-WMT	RE1-WBN	RE1-WMA	RE1-WST	RE1-VMT	RE1-VBN	RE1-VMA	RE1-VST	RE1-TMT	RE1-TBN	RE1-TMA	RE1-TST	3	12		
RE2	RE2-MT	RE2-BN	RE2-MA	RE2-WMT	RE2-WBN	RE2-WMA	RE2-WST	RE2-VMT	RE1-VBN	RE2-VMA	RE2-VST	RE2-TMT	RE2-TBN	RE2-TMA	RE2-TST	3	12		
RE3	RE3-MT	RE3-BN	RE3-MA	RE3-WMT	RE3-WBN	RE3-WMA	RE3-WST	RE3-VMT	RE3-VBN	RE3-VMA	RE3-VST	RE3-TMT	RE3-TBN	RE3-TMA	RE3-TST	3	12		
RE4	RE4-MT	RE4-BN	RE4-MA	RE4-WMT	RE4-WBN	RE4-WMA	RE4-WST	RE4-VMT	RE4-VBN	RE4-VMA	RE4-VST	RE4-TMT	RE4-TBN	RE4-TMA	RE4-TST	3	12		
RE5	RE5-MT	RE5-BN	RE5-MA	RE5-WMT	RE5-WBN	RE5-WMA	RE5-WST	RE5-VMT	RE5-VBN	RE5-VMA	RE5-VST	RE5-TMT	RE4-TBN	RE5-TMA	RE5-TST	3	12		
RE6	RE6-MT	RE6-BN	RE6-MA	RE6-WMT	RE6-WBN	RE6-WMA	RE6-WST	RE6-VMT	RE6-VBN	RE6-VMA	RE6-VST	RE6-TMT	RE6-TBN	RE6-TMA	RE6-TST	3	12		
RE7	RE7-MT	RE7-BN	RE7-MA	RE7-WMT	RE7-WBN	RE7-WMA	RE7-WST	RE7-VMT	RE7-VBN	RE7-VMA	RE7-VST	RE7-TMT	RE7-TBN	RE7-TMA	RE7-TST	3	12		
RE8	RE8-MT	RE8-BN	RE8-MA	RE8-WMT	RE8-WBN	RE8-WMA	RE8-WST	RE8-VMT	RE8-VBN	RE8-VMA	RE8-VST	RE8-TMT	RE8-TBN	RE8-TMA	RE8-TST	3	12		
RE9	RE9-MT	RE9-BN	RE9-MA	RE9-WMT	RE9-WBN	RE9-WMA	RE9-WST	RE9-VMT	RE9-VBN	RE9-VMA	RE9-VST	RE9-TMT	RE9-TBN	RE9-TMA	RE9-TST	3	12		
	EB3-U			EB4-W			PT4-W	EB5-V			PT5-V	EB6-T			PT6-T			3	3
Red Dog Caribou																			
CS1	CS1-MT	CS1-BN	CS1-MA	CS1-WMT	CS1-WBN	CS1-WMA	CS1-WST	CS1-VMT	CS1-VBN	CS1-VMA	CS1-VST	CS1-TMT	CS1-TBN	CS1-TMA	CS1-TST	3	12		
CS2	CS2-MT	CS2-BN	CS2-MA	CS2-WMT	CS2-WBN	CS2-WMA	CS2-WST	CS2-VMT	CS2-VBN	CS2-VMA	CS2-VST	CS2-TMT	CS2-TBN	CS2-TMA	CS2-TST	3	12		
CS3	CS3-MT	CS3-BN	CS3-MA	CS3-WMT	CS3-WBN	CS3-WMA	CS3-WST	CS3-VMT	CS3-VBN	CS3-VMA	CS3-VST	CS3-TMT	CS3-TBN	CS3-TMA	CS3-TST	3	12		
CS4	CS4-MT	CS4-BN	CS4-MA	CS4-WMT	CS4-WBN	CS4-WMA	CS4-WST	CS4-VMT	CS4-VBN	CS4-VMA	CS4-VST	CS4-TMT	CS4-TBN	CS4-TMA	CS4-TST	3	12		
CS5	CS5-MT	CS5-BN	CS5-MA	CS5-WMT	CS5-WBN	CS5-WMA	CS5-WST	CS5-VMT	CS5-VBN	CS5-VMA	CS5-VST	CS5-TMT	CS5-TBN	CS5-TMA	CS5-TST	3	12		
CS6	CS6-MT	CS6-BN	CS6-MA	CS6-WMT	CS6-WBN	CS6-WMA	CS6-WST	CS6-VMT	CS6-VBN	CS6-VMA	CS6-VST	CS6-TMT	CS6-TBN	CS6-TMA	CS6-TST	3	12		
CS7	CS7-MT	CS7-BN	CS7-MA	CS7-WMT	CS7-WBN	CS7-WMA	CS7-WST	CS7-VMT	CS7-VBN	CS7-VMA	CS7-VST	CS7-TMT	CS7-TBN	CS7-TMA	CS7-TST	3	12		
CS8	CS8-MT	CS8-BN	CS8-MA	CS8-WMT	CS8-WBN	CS8-WMA	CS8-WST	CS8-VMT	CS8-VBN	CS8-VMA	CS8-VST	CS8-TMT	CS8-TBN	CS8-TMA	CS8-TST	3	12		
CS9	CS9-MT	CS9-BN	CS9-MA	CS9-WMT	CS9-WBN	CS9-WMA	CS9-WST	CS9-VMT	CS9-VBN	CS9-VMA	CS9-VST	CS9-TMT	CS9-TBN	CS9-TMA	CS9-TST	3	12		
	EB7-U			EB7-W			PT7-W	EB8-V			PT8-V	EB9-T			PT9-T			3	3
Reference Caribou																			
CR1	CR1-MT	CR1-BN	CR1-MA	CR1-WMT	CR1-WBN	CR1-WMA	CR1-WST	CR1-VMT	CR1-VBN	CR1-VMA	CR1-VST	CR1-TMT	CR1-TBN	CR1-TMA	CR1-TST	3	12		
CR2	CR2-MT	CR2-BN	CR2-MA	CR2-WMT	CR2-WBN	CR2-WMA	CR2-WST	CR2-VMT	CR2-VBN	CR2-VMA	CR2-VST	CR2-TMT	CR2-TBN	CR2-TMA	CR2-TST	3	12		
CR3	CR3-MT	CR3-BN	CR3-MA	CR3-WMT	CR3-WBN	CR3-WMA	CR3-WST	CR3-VMT	CR3-VBN	CR3-VMA	CR3-VST	CR3-TMT	CR3-TBN	CR3-TMA	CR3-TST	3	12		
CR4	CR4-MT	CR4-BN	CR4-MA	CR4-WMT	CR4-WBN	CR4-WMA	CR4-WST	CR4-VMT	CR4-VBN	CR4-VMA	CR4-VST	CR4-TMT	CR4-TBN	CR4-TMA	CR4-TST	3	12		
CR5	CR5-MT	CR5-BN	CR5-MA	CR5-WMT	CR5-WBN	CR5-WMA	CR5-WST	CR5-VMT	CR5-VBN	CR5-VMA	CR5-VST	CR5-TMT	CR5-TBN	CR5-TMA	CR5-TST	3	12		
CR6	CR6-MT	CR6-BN	CR6-MA	CR6-WMT	CR6-WBN	CR6-WMA	CR6-WST	CR6-VMT	CR6-VBN	CR6-VMA	CR6-VST	CR6-TMT	CR6-TBN	CR6-TMA	CR6-TST	3	12		
CR7	CR7-MT	CR7-BN	CR7-MA	CR7-WMT	CR7-WBN	CR7-WMA	CR7-WST	CR7-VMT	CR7-VBN	CR7-VMA	CR7-VST	CR7-TMT	CR7-TBN	CR7-TMA	CR7-TST	3	12		
CR8	CR8-MT	CR8-BN	CR8-MA	CR8-WMT	CR8-WBN	CR8-WMA	CR8-WST	CR8-VMT	CR8-VBN	CR8-VMA	CR8-VST	CR8-TMT	CR8-TBN	CR8-TMA	CR8-TST	3	12		
	EB5-U			EB10-W			PT10-W	EB11-V			PT11-V	EB12-T			PT12-T			3	3
							Total Cooking Study Samples (meat, bone, marrow, soup, equipment blanks, pot blanks):								**445**		**420**	12	13
							Pre-Cooking Study Samples (ingredients: water, vinegar, tomato, salt; equipment blanks, pot blanks):								24	12		9	3
							Total Pre-Cooking Study Samples (ingredients, uncooked meat, bone, marrow, equipment blanks, pot blanks):								129	105			
							Grand Total Samples:								**598**				

Notes:

Other Ingredients - Ingredients were collected and analyzed as part of the pre-study screening (distilled water, salt, vinegar, and tomato paste)

Slow Cooker Blanks - 40 oz lab grade deionized water (DI) was heated in a clean slow cooker for the same length of cooking time per soup recipe (part of the pre-study equipment screening)

CS = Caribou from Red Dog vicinity (site); CR = caribou from reference area; BE = beef; RE= reindeer; MT = meat; BN = bone; MA = marrow; ST = stew (soup); DI = deionized water; W = water; V = vinegar; T = tomato paste; S = Salt

EB = Equipment Blank - rinsate blanks collected from decontaminated equipment prior to sample collection; collection frequency was one per meat source per uncooked and soup recipe

PT = Pot Control Blanks - contain the soup ingredients with no meat, marrow, or bone; collected 1 per day per soup recipe

Each caribou sample (CR1, CR2, CR3…; CS1, CS2, CS3…) is also used in each cooking preparation (water, vinegar, tomato)

Table 4. Statistical comparisons of metal concentrations in raw and cooked animal tissues in soups

		Raw		Water Base		Tomato Base		Vinegar Base			Significant
Analyte	**Animal**	**Mean**	**%ND**	**Mean**	**%ND**	**Mean**	**%ND**	**Mean**	**%ND**	**P-Value[a]**	**Differences**
Lead											
Meat											
	Red Dog Caribou	0.040	0%	0.040	0%	0.051	0%	0.033	0%	0.958	none
	Reference Caribou	0.031	0%	0.064	0%	0.018	0%	0.11	0%	0.229	none
	Reindeer	0.0072	44%	0.0017	0%	0.013	67%	0.0056	67%	0.014	W<T
	Store-bought Beef	0.0061	22%	0.0035	0%	0.0033	22%	0.0041	0%	0.502	none
Marrow											
	Red Dog Caribou	0.0080	18%	0.0090	64%	0.010	9%	0.0077	0%	0.455	none
	Reference Caribou	0.0041	17%	0.0088	0%	0.0084	33%	0.012	0%	0.364	none
	Reindeer	0.0065	50%	0.0080	44%	0.0081	86%	0.0070	71%	0.639	none
	Store-bought Beef	0.0065	44%	0.013	0%	0.011	0%	0.015	0%	0.036	[b]
Bone											
	Red Dog Caribou	0.70	0%	0.69	0%	0.70	0%	0.68	0%	0.995	none
	Reference Caribou	0.51	0%	0.53	0%	0.48	0%	0.56	0%	0.990	none
	Reindeer	0.26	0%	0.28	0%	0.23	0%	0.28	0%	0.685	none
	Store-bought Beef	0.18	0%	0.20	0%	0.18	0%	0.17	0%	0.835	none
Broth											
	Red Dog Caribou	--		0.0093	0%	0.0091	0%	0.0035	0%	0.216	none
	Reference Caribou	--		0.0095	0%	0.0017	0%	0.014	0%	0.144	none
	Reindeer	--		0.00029	0%	0.00023	33%	0.0021	56%	0.301	none
	Store-bought Beef	--		0.00034	0%	0.00028	11%	0.00021	0%	0.179	none
Zinc											
Meat											
	Red Dog Caribou	48.5	0%	91.4	0%	80.8	0%	83.9	0%	<0.0001	Raw<W,T,V
	Reference Caribou	44.0	0%	94.5	0%	74.5	0%	84.6	0%	<0.0001	Raw<W,T,V
	Reindeer	46.5	0%	73.2	0%	68.6	0%	78.9	0%	<0.0001	Raw<W,T,V
	Store-bought Beef	41.8	0%	67.6	0%	75.9	0%	82.4	0%	<0.0001	Raw<W,T,V
Marrow											
	Red Dog Caribou	2.0	0%	2.6	0%	3.2	0%	2.9	0%	0.282	none
	Reference Caribou	2.8	0%	2.8	0%	4.7	0%	3.9	0%	0.355	none
	Reindeer	3.0	0%	1.7	0%	2.1	0%	2.7	0%	0.016	Raw>W
	Store-bought Beef	2.8	0%	13.6	0%	13.3	0%	14.4	0%	<0.0001	Raw<W,T,V
Bone											
	Red Dog Caribou	90.3	0%	90.9	0%	86.1	0%	90.8	0%	0.792	none
	Reference Caribou	85.3	0%	87.3	0%	68.3	0%	88.6	0%	0.089	none
	Reindeer	64.3	0%	70.2	0%	56.3	0%	73.8	0%	0.016	T<W,V
	Store-bought Beef	61.7	0%	62.6	0%	64.0	0%	62.1	0%	0.831	none
Broth											
	Red Dog Caribou	--		2.69	0%	2.40	0%	2.74	0%	0.759	none
	Reference Caribou	--		2.39	0%	2.03	0%	2.39	0%	0.960	none
	Reindeer	--		4.04	0%	1.97	0%	5.98	0%	0.005	T<W,V
	Store-bought Beef	--		2.45	0%	1.93	0%	1.74	0%	0.521	none
Cadmium											
Meat											
	Red Dog Caribou	0.0044	0%	0.0073	0%	0.0081	0%	0.0076	0%	0.009	Raw<W,T,V
	Reference Caribou	0.0029	0%	0.0057	0%	0.0054	0%	0.0068	0%	0.041	Raw<V
	Reindeer	0.0021	0%	0.0029	0%	0.0033	0%	0.0029	0%	0.179	none
	Store-bought Beef	0.0031	100%	0.00051	100%	0.0034	100%	0.0037	100%	<0.0001	W<Raw,T,V
Marrow											
	Red Dog Caribou	0.0043	27%	0.0060	55%	0.0054	27%	0.0060	36%	0.139	none
	Reference Caribou	0.0039	50%	0.0038	33%	0.0056	33%	0.0053	50%	0.413	none
	Reindeer	0.0085	100%	0.0085	100%	0.0084	100%	0.0076	86%	0.338	none
	Store-bought Beef	0.0088	100%	0.00089	75%	0.0035	25%	0.0043	100%	<0.0001	Raw>W,T,V; W<T,V
Bone											
	Red Dog Caribou	0.0089	100%	0.0076	82%	0.0050	36%	0.0066	64%	0.006	Raw>T
	Reference Caribou	0.0083	100%	0.0081	100%	0.0055	67%	0.0060	50%	0.103	none
	Reindeer	0.0074	89%	0.0086	100%	0.0064	78%	0.0078	89%	0.340	none
	Store-bought Beef	0.0090	100%	0.0027	44%	0.0087	100%	0.0088	100%	<0.0001	W<Raw,T,V
Broth											
	Red Dog Caribou	--		0.00045	0%	0.00059	0%	0.00034	0%	0.024	T>V
	Reference Caribou	--		0.00050	0%	0.00040	0%	0.00065	0%	0.944	none
	Reindeer	--		0.00018	0%	0.00028	0%	0.00032	11%	0.151	none
	Store-bought Beef	--		0.00006	100%	0.00025	67%	0.00025	100%	<0.0001	W<T,V

Notes: Mean (arithmetic average) concentrations reported in mg/kg wet weight.
Statistical comparisons based on log-transformed concentrations with results qualified as undetected included at half the reporting limit.
[shaded] Half or more of the results were qualified as not detected; statistical comparisons may not be reliable
[a] P-values by animal are from ANOVA for sample types and Tukey's honest sigficant differences at 95% confidence.
[b] Tukey's did not identy any differences as significant at 95% confidence despite the ANOVA P-value <0.05.

%ND - Percent of results qualified as not detected
ANOVA - Analysis of variance
none - No statistically significant differences (P>0.05)
Raw - Uncooked tissue
T - Tomato-based soup
V - Vinegar-based soup
W - Water-based soup