ENVIRONMENTAL MONITORING AT THE FORMER LEAD/ZINC MINE MAARMORILIK, NORTH-WEST GREENLAND, IN 2022

Metal concentrations in blue mussels (*Mytilus* spp.) in relation to pollution trends and dietary limits

Scientific Report from DCE – Danish Centre for Environment and Energy No. 648 2025

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Data sheet

Series title and no.:	Scientific Report from DCE – Danish Centre for Environment and Energy No. 648
Category:	Scientific advisory report
Title:	Environmental monitoring at the former lead/zinc mine Maarmorilik, Northwest Greenland, in 2022
Subtitle:	Metal concentrations in blue mussels (*Mytilus* spp.) in relation to pollution trends and dietary limits
Author(s):	Anne Mette Bagger, Jens Søndergaard and Lis Bach
Institution(s):	Aarhus University, DCE - Danish Centre for Environment and Energy
Publisher:	Aarhus University, DCE – Danish Centre for Environment and Energy ©
URL:	https://dce.au.dk/en
Year of publication:	2025
Editing completed:	February 2025
Referee(s):	Anders Mosbech
Quality assurance, DCE:	Kirsten Bang
Greenlandic translation:	Kelly Berthelsen
External comments:	The comments can be found here:
Financial support:	Environmental Agency for Mineral Resource Activities, Government of Greenland
Please cite as:	Bagger A.M., Søndergaard, J. & Bach, L. 2025, Environmental monitoring at the former lead/zinc mine Maarmorilik, Northwest Greenland, in 2022. Metal concentrations in blue mussels (*Mytilus* spp.) in relation to pollution trends and dietary limits. Aarhus University, DCE – Danish Centre for Environment and Energy, 24 pp. Scientific Report No. 648

Abstract: In 2022, environmental monitoring was carried out at the former lead/zinc mine Maarmorilik, Northwest Greenland, which was active during 1973-1990. Samples of sediment and blue mussels were collected and analysed. The study shows there still is an impact from the previous mining operation, and that lead levels exceeds the Greenland regulatory limit for trading mussels as a human dietary items at a distance of ~15 km from the mine site. Overall, the pollution level remains unchanged since last monitoring in 2009.

Keywords:	Environmental monitoring, mining, lead, zinc, Maarmorilik
Front page photo:	Blue mussels in the fjord Affarlikassaa with Maarmorilik in the background. Photo: Lis Bach
ISBN:	978-87-7156-937-7
ISSN (electronic):	2244-9981
Number of pages:	24
Internet version:	SR648.pdf

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Preface

The monitoring was conducted as a part of a scientific research project financed by Environmental Agency for Mineral Resource Activities (EAMRA) and Ministry of Higher Education and Science. Other outputs from the project include the Regional Uummannap Kangerlua and Sigguup Nunaa (Svartenhuk) - environmental baseline assessment for mining activities (Fritt-Rasmussen et al. 2025)

Sammenfatning

Fra 1973 til 1990 blev bly- (Pb) og zink- (Zn) malm udvundet ved Maarmorilik i Uummannaq-området. Malmforekomsterne fandtes primært i et bjerg kendt som 'Den Sorte Engel' i ca. 600 meters højde over havets overflade. Den udvundne malm blev transporteret via svævebane over Affarlikassaa Fjorden til et forarbejdningsanlæg i Maarmorilik. Det producerede Pb- og Zn-koncentrat blev derefter lastet ombord på skibe og transporteret til smelteværker i Europa.

Siden 1972 er der blevet udført miljøundersøgelser omkring minen og i de omgivende fjorde for at overvåge eventuelle miljøpåvirkninger fra minen. Undersøgelserne omfattede havvand, sedimenter og en række organismer, herunder tang, muslinger, fisk, rejer og lav.

Under minedriften blev forskellige forureningskilder identificeret. Knusning af malm og transport af koncentrat skabte støv, som blev spredt til omgivelserne. Gråbjergsdumpe var både ophav til støvspredning og udvaskning af Pb og Zn til det omkringliggende havmiljø, især i fjordene Affarlikassaa og Qaamarujuk der ligger tættest på minen. Den mest betydelige kilde til forurening, trods forbedrende drifts tiltag, var dog mineaffaldet 'mine tailings', som blev udledt til Affarlikassaa-fjorden.

Denne rapport præsenterer resultaterne af miljøundersøgelserne af blåmuslinger foretaget i 2022, – mere end 30 år efter ophør af minedriften. Området er senest moniteret i 2009.

Miljøundersøgelserne viser forhøjede Pb- og Zn-koncentrationer i både små, mellem og store blåmuslinger (3 - >6 cm) fra Affarlikassaa- og Qaamarujuk-fjordene i an afstand på ca. 12-15 km fra minen sammenlignet med en reference station beliggende ca. 40 km fra minen. Ligeledes findes der forhøjede koncentrationer af Pb og Zn i sedimenter tæt ved minen. Koncentrationer af Pb- og Zn i muslinger og sedimenter er aftagende med stigende afstand fra minen. Disse fund viser, at metalniveauerne i fjordene ved Maarmorilik overordnet set er uændrede siden sidste monitering i 2009 og dermed fortsat er forhøjede mere end 30 år efter minens lukning på grund af den historiske forurening fra mineområdet.

Da blåmuslinger indsamles og konsumeres af den lokale befolkning i Grønland, blev metalindholdet sammenlignet med den grønlandske grænseværdi for Pb for detailhandel af muslinger som fødevare for mennesker. Den maksimale koncentrationsgrænse for indtag blev overskredet i både små og store muslinger ved alle overvågede stationer i Affarlikassaa- og Qaamarujuk-fjordene.

Samlet konkluderes det, at påvirkningen fra minedriften ikke er ændret siden 2009 og fortsat er betydelig i 2022 i fjordene Affarlikassaa og Qaamarujuk inden for en afstand af mellem 12 og 15 km fra minen.

Summary

From 1973 to 1990, lead (Pb) and zinc (Zn) ore was mined at Maarmorilik in the Uummannaq area. The ore deposits were primarily found in a mountain known as 'The Black Angel' at approximately 600 meters above sea level. The mined ore was transported via cable car across the Affarlikassaa Fjord to a processing plant in Maarmorilik. The produced Pb and Zn concentrate was then loaded onto bulk carriers and transported to smelters in Europe.

Since 1972, environmental studies have been conducted around the mine and in the surrounding fjords to monitor any environmental impacts from the mine. The studies included seawater, sediments, and a range of organisms, including seaweed, mussels, fish, shrimp, and lichens.

During mining operations, various sources of pollution were identified. Crushing of ore and transport of concentrate created dust, which spread to the surroundings. Waste rock dumps were both sources of dust dispersion and leaching of Pb and Zn into the surrounding marine environment, especially in the Affarlikassaa and Qaamarujuk fjords closest to the mine. The most significant source of pollution, despite operational improvements, was the mine tailings, which were discharged into the Affarlikassaa Fjord.

This report presents the results of environmental studies of blue mussels conducted in 2022, more than 30 years after mining ceased. The area was last monitored in 2009.

The environmental study show elevated Pb and Zn concentrations in both small, medium and large sized blue mussels (3 - >6 cm) from the Affarlikassaa and Qaamarujuk fjords in a distance of approximately 12-15 km from the mine compared to a reference station located approximately 40 km from the mine. Similarly, elevated concentrations of Pb and Zn are found in sediments close to the mine. Concentrations of Pb and Zn in mussels and sediments decrease with increasing distance from the mine. These findings show that metal levels in the fjords at Maarmorilik are largely unchanged since the last monitoring in 2009 and thereby remain elevated more than 30 years after the mine's closure due to historical contamination from the mining area.

As blue mussels are collected and consumed by the local population in Greenland, the metal content was compared to the Greenlandic limit value for Pb for retail trade of mussels as dietary items for humans. The maximum concentration limit for intake was exceeded in both small and large mussels at all monitored stations in the Affarlikassaa and Qaamarujuk fjords.

In conclusion, the impact from mining operations remains in 2022 significant in the Affarlikassaa and Qaamarujuk fjords within a distance of 12 to 15 km from the mine.

Eqikkaaneq

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1 Introduction

Between 1973 and 1990, Maarmorilik in Northwest Greenland was a significant site for the extraction of lead (Pb) and zinc (Zn) ore. This mining operation was situated within a vast fjord system, Qaamarujuk Fjord system, with the nearest settlement, Ukkussissat, located approximately 25 km to the west and the primary town, Uummannaq, about 80 km away. The mining activities at Maarmorilik caused profound environmental implications, especially concerning heavy metal pollution in the surrounding fjord systems (Figure 1).

Figure 1. Map of the area of the former Maarmorilik mine.

The Pb/Zn ore was mined from the 'Black Angel' mountain at an altitude of about 600 meters. The ore was transported via cable cars across the Affarlikassaa fjord to a flotation plant, where Pb and Zn concentrates were produced. These concentrates were then loaded and transported in bulk carriers to European smelting plants. During the mining operation, 11 million tons ore were extracted, leaving behind ~8 million tons of tailings (the by-product of ore processing) containing elevated concentrations of iron (Fe), copper (Cu), arsenic (As), silver (Ag), zinc (Zn), cadmium (Cd), mercury (Hg) and lead (Pb)). The tailings were discharged at a depth of 30 meters, settling at around 50-60 meters in the nearby Affarlikassaa fjord. The rationale for using this fjord as a tailings deposit was its partial separation from the outer Qaamarujuk fjord by a sill at the fjord mouth, which was expected to contain the tailings within the fjord. Waste rock (totaling 2–3 million tons) from excavation of the mine tunnels, which also contained elevated metal concentrations, were deposed of outside the mine on four major dumps outside on the Black Angel mountain slopes.

In the early years of mining, monitoring studies showed that pollution was more significant than expected from the environmental studies conducted pre-mining. Surprisingly increasing amounts of dissolved heavy metals (particularly Pb, Zn and Cadmium (Cd)) were measured in the fjord water around Maarmorilik. Comprehensive environmental studies pointed to the disposal of tailings into Affarlikassaa Fjord to be significant sources of pollution to the surrounding area due to a combination of metals dissolving from the tailings and seasonal transport of pollutants from the Affarlikassaa Fjord to the Qaamarujuk Fjord as a result of complex hydrographical processes which had not been foreseen. The key hydrological processes for dispersion of pollutants from the Affarlikassaa Fjord were seasonal vertical mixing of the water layers in the Affarlikassaa Fjord and complete flushing of pollutants from the fjord during some winters due to in- and outgoing currents (summerized in Søndergaard and Mosbech, 2022). These processes were not anticipated in the studies conducted before the mining operations. It has been estimated that approximately 200 tons of Pb and 300 tons of Zn accumulated outside the Affarlikassaa Fjord since the onset of tailings discharge (Elberling et al., 2002).

Additionally, residues from the mining processing and waste rock deposits were identified as sources of pollution (Johansen et al. 2010). Notably, the major waste rock dump of about 400,000 tons reached the tidal zone causing the highest lead and zinc levels in seaweed and mussels in the area but also lead to major dispersal of elements as dust by atmospheric transport (Søndergaard et al., 2013).

As a result of the pollution, the authorities requested the mining company to improve the environmental situation, the main culprits of the pollution being tailings and waste dumps. A number of measures were undertaken, and from 1978 to 1985 the lead content of the tailings was reduced due to technical improvements from 0.44% to 0.15%, zinc content from 1.10% to 0.23% and cadmium content from 57 to 14 ppm. Also, of the four waste dumps totalling 2–3 million tons with 0.1–0.8% Pb and 0.3–2.3% Zn that had been disposed outside the mine in its first 10 years of operation, one of these dumps of c. 400,000 tons reached into the tidal zone. During mine closure in the summer of 1990, efforts were made to remove this dump as much as possible, with ~90% of the material being deposited partly into the Affarlikassaa Fjord on top of the tailings, and partly on land within the former concentrate storage building (Søndergaard and Mosbech 2022).

Environmental pollution from the mining activities was monitored throughout the operation and continued after the mine's closure (Grønlands Miljøundersøgelser 1988; Johansen et al., 1997, 1998, 1999, 2003, 2006, 2008, 2010; Rigét et al., 1996; Møller et al., 2002; Schiedek et al., 2009). Monitoring included, among other samples, regular sampling and chemical analysis of biota (mussels, seaweed, and lichens) which served as key monitoring species for marine and air pollution, respectively. As anticipated, the studies show following mine closure, a marked decline of pollution over time. However, the latest findings from regular monitoring in 2008 (Schiedek et al., 2009) and 2009 (Johansen et al., 2010), further analysed in (Søndergaard et al., 2010, 2011) using Pb isotope tracing, concluded that Pb levels in blue mussels have remained elevated due to dispersion of mine-related Pb in the Affarlikassaa and Qaamarujuk fjords within at least 12 km from the mine. In contrast, elevated Zn concentrations were limited to a smaller area near Maarmorilik.

Blue mussels have been extensively utilized to monitor heavy metal pollution and bioaccumulation in marine environments. Blue mussels are used worldwide as biomonitoring species due to their filter-feeding behavior and ability to bioaccumulate metals from sediments, water, and food particles. In Maarmorilik, they have played a crucial role in assessing the impact of mining operations both during active and post-closure mining. Sampling resident mussels, which have spent their entire lives at the collection site, primarily aimed to evaluate the spatial and temporal pollution trends, whereas mussels transplanted from a reference site into a polluted site was conducted during monitoring in 2008, 2009 and 2010 and aimed to privide knowledge of the recent pollution status.

This report presents the results of fieldwork carried out in 2022. The objective of this document is to update knowledge on the spatial concentrations of Pb and Zn in blue mussels (*Mytilus spp*) in the vicinity of the mine at Maarmorilik, with a specific focus on their relevance to human consumption. Additionally, it was investigated to what extent the size of the blue mussels affected the metal concentrations, and the temporal trends since mine closure were evaluated.

2 Sampling

Sampling was conducted in August 2022, using local boat charters from Uummannaq and sampling locations are shown in Figure 2.

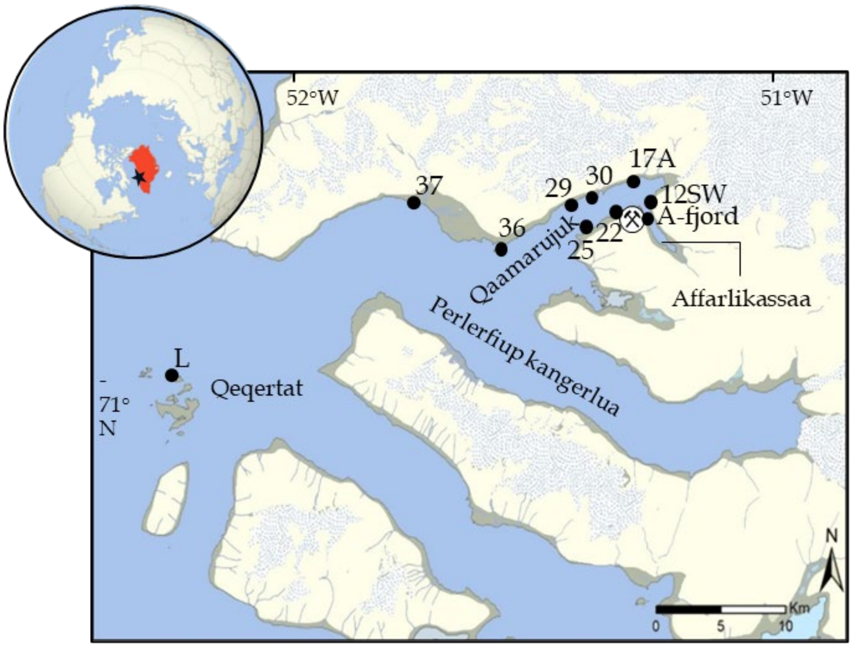


Figure 2. Sampling stations (A-fjord, 12SW, 17A, 22, 25, 29, 30, 36, 37, and L) visited in 2022 during the environmental monitoring for pollution in the area of the former Maarmorilik mine.

Beach sediment samples were collected from shore at the intertidal zone at nine different sites (st 12SW, 17A, 22, 25, 29, 30, 36, 37, and L) within the fjord system at Maarmorilik from shore using a stainless-steel spoon. Sediment was not collected at st. A-fjord due to the natural conditions of the substratum i.e. rocks and boulders. The sediment samples were stored frozen in PE ziplock bags until analyses.

Blue mussels, *Mytilus* spp. were collected from ten sites (st. A-fjord, 12SW, 17A, 22, 25, 29, 30, 36, 37, and L). In the Maarmorilik fjord system, both *Mytilus edulis* and *Mytilus trossulus*, along with hybrids of these, are known to occur (Wenne et al., 2016). However, species-level identification was not conducted in this study. The mussels were sampled by hand at low tide and sorted at site into three size classes according to their shell length: 3 cm (2.7-3.3 cm), 5 cm (4.7-5.3 cm), and >6 cm, each size class containing 20 mussels. Two sets of mussels were sampled at each site, one set was left to depurate for 24 h according to the methods described in (Bach et al., 2023) and another set was left un-depurated. For st. L and 25, only depurated mussels were included in the analyses (unfortunately, the non-depurated samples were lost). The mussels were transported to the laboratory facilities at Ecoscience, Aarhus University in Roskilde for further processing. In the laboratory, the adductors of the mussels were cut, and the shells were opened. The mussels were allowed to drain before the soft parts were cut out with a stainless-steel scalpel. The soft parts of each size group were pooled (20 specimens) and then deep-frozen until element analyses.

3 Analytical methods

All samples were freeze-dried, and the blue mussels were further homogenized in an agate mortar before acid digestion.

A subsample of 300 mg blue mussel or 200 mg sediment, was digested in a mixture of 4 ml concentrated Merck Suprapure nitric acid and 4 ml milliQ water in Teflon bombs in an Anton Paar Multiwave 7000 Microwave Oven following the DS259 method. Blanks, duplicates, and certified reference materials (DORM, DOLT, and TORT) were included with the samples for quality assurance and quality control (QA/QC). Following the digestion, solutions were diluted to 60 g with milliQ water and stored in polyethylene bottles until analysis.

Digestion solutions were analyzed by an Agilent 7900 ICP-MS for ca. 60 elements, of which only Pb and Zn are reported in the present report.

4 Results and discussion

4.1 Sediment

As part of the environmental monitoring program, marine sediment samples were collected from the Affarlikassaa, Qaamarujuk, and Perlerfiup kangerlua fjords as well as at Qeqertat and analyzed for elemental composition with particular focus on Pb and Zn (Figure 2). These sediment samples provide valuable insights into metal pollution levels and allow for monitoring the environmental impacts of the fjords.

4.1.1 Spatial trends in Pb and Zn concentrations in sediment

The sediment samples collected in 2022 (Table 1) showed high concentrations of 1877 µg/g Pb and 3415 µg/g Zn at st. 12SW, located at the foot of the Black Angel Mountain, where the old waste rock dump was located. Concentrations at this station exceeded the Norwegian environmental quality standards (EQS) for sediment at level IV, indicating a risk of acute toxic effects on biota even with short-term exposure to these sediment levels as defined by Miljødirektoratet (2016). Pb and Zn concentrations in sediment samples from st. 17A, located across the waste rock dump on the other side of Qaamarujuk, decreased markedly to concentrations ranging in EQS level II and III, indicating good to moderate conditions. Metal concentrations generally decreased with increasing distance from the mine, with the lowest concentrations found at st. L, used as a reference for natural background conditions at Qeqertat, located approximately 40 km from the mine. At this station, Pb and Zn concentrations were measured at 3.0 and 10.9 µg/g, respectively.

Table 1. Pb and Zn concentrations (µg/g dry weight) in sediments across stations in the area of Maarmorilik collected in 2022 and Norwegian environmental quality standards (EQS) for sediment (µg/g dry weight). NA: No sediment could be collected at st A-fjord as the collection site is of boulder character.

	Pb	Zn
Maarmorilik stations		
L	3.0	10.9
37	10.5	94.3
36	9.9	49.4
30	18.7	83.3
29	12.0	58.9
25	11.2	42.8
22	9.2	67.3
17A	53.4	196.1
A-fjord	NA	NA
12SW	1876.7	3415.2
Norwegian environmental quality standards (EQS) for sediment		
Background level (I)	0-25	0-90
Good (II)	25-150	90-139
Moderate (III)	150-1480	139-750
Bad (IV)	1480-2000	750-6690
Very bad (V)	2000-2500	>6690

These results demonstrate that metal concentrations in sediment collected from st. 12SW remain elevated and is of 'bad environmental quality (IV)' according to the Norwegian EQS. The primary source of pollution is hence attributed to the waste dumps and residual materials deposited on the slopes and shoreline of Black Angel Mountain.

4.2 Blue mussels

Blue mussels have been extensively utilized to monitor heavy metal pollution and bioaccumulation in marine environments. In Maarmorilik, they have been included in the environmental monitoring program and have played a key role in assessing the impact of the mining operation both during active mining and post-closure.

4.2.1 Spatial trends of Pb and Zn concentrations in blue mussels

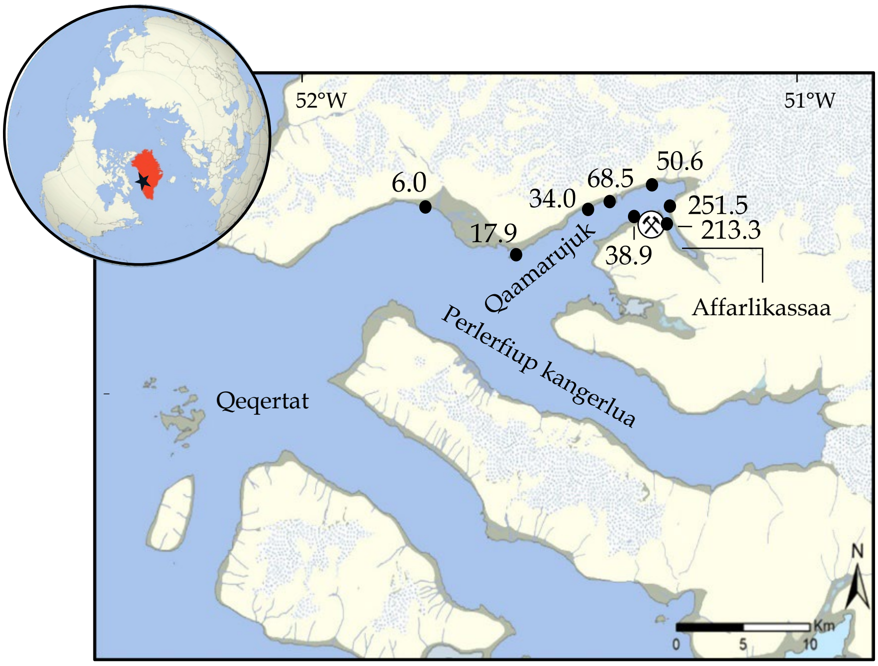
The Pb and Zn concentrations measured in the non-depurated blue mussel samples (each consisting of 20 individuals, ~5 cm shell length as a standard length) collected during 2022 across stations are shown in Table 2, Figures 3 and 4.

Table 2. Pb and Zn concentrations (µg/g dry weight) in blue mussels (5 cm) across stations in the area of Maarmorilik collected in 2022. NA: Samples from st L and 25 were not analysed as samples were lost.

Maarmorilik stations	Pb	Zn
L	NA	NA
37	6.0	133.4
36	17.9	160.0
30	68.5	221.2
29	34.0	163.5
25	NA	NA
22	38.9	223.8
17A	50.6	228.6
A-fjord	213.3	627.8
12SW	251.5	591.2

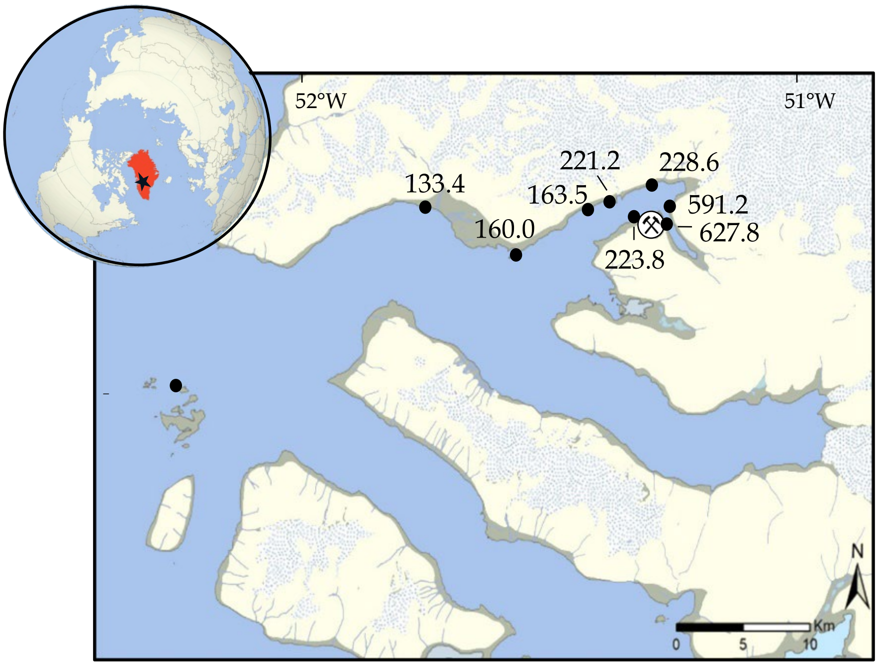
The trends in metal concentration in mussels corresponded to the observations in sediment samples (Table 1), with the highest metal concentrations found at st. 12SW with a concentration of 251.5 µg/g dry weight, and decreasing concentrations with increasing distance from the mine. The lowest concentration was found at the sampling station furthest from the source at st 37 (6.0 µg/g dry weight).

Figure 3. Pb concentrations (µg/g dry weight) in resident non-depurated blue mussel samples each consisting of 20 individuals with~5 cm shell length across stations in the area of Maarmorilik collected in 2022.



The Zn concentrations measured in the blue mussel samples are presented in Figure 4. A similar trend to that observed for Pb concentrations was evident for Zn, with the highest concentrations of 627.8 µg/g dry weight detected at st. A-fjord, located at the former tailings outlet in Affarlikassaa fjord. Concentrations decreased with increasing distance to the mine with the station furthest from the mine with the lowest concentration.

Figure 4. Zn concentrations (µg/g dry weight) in resident blue mussel samples each consisting of 20 individuals with ~ 5 cm shell lenght across stations in the area of Maarmorilik collected in 2022.



4.2.2 Temporal trends of Pb and Zn concentrations in blue mussels

While environmental studies in Maarmorilik have been performed since 1972, a systematic monitoring of Pb and Zn pollution was initiated in 1982. Temporal Pb and Zn concentrations in non-depurated mussels is presented in Figure 5 and 6 with an added best fitted trendline to the data. At the reference station (st. L), the Pb and Zn concentrations is within a low level (data for 2022 is missing due to loss of samples), reflecting the natural baseline levels and the site's unaffected condition. At the monitoring stations in Qaamarujuk and Perlerfiup kangerlua (st 37, 36, 29, 25, 30, 17A, 22 and 12SW (st A-fjord excluded as it has not been monitored systematically)), the Pb and Zn concentrations overall decreased significantly after 1988. However, at st. 12SW, the most contaminated station closest to the mine waste deposits, Pb concentrations increased from 154.8 µg/g in 2007 to 251.5 µg/g in 2022. Notably, Zn levels in 2022 reached 591.2 µg/g, surpassing the concentrations observed in 1988 (547 µg/g). A possible explanation for the most varying results at site st. 12SW over time may be that st. 12SW is situated right in the major waste dump area and therefore is likely to be affected by small-scale differences in leaching from the mine waste etc., whereas sites situated further away may be more representative for an overall pollution pattern.

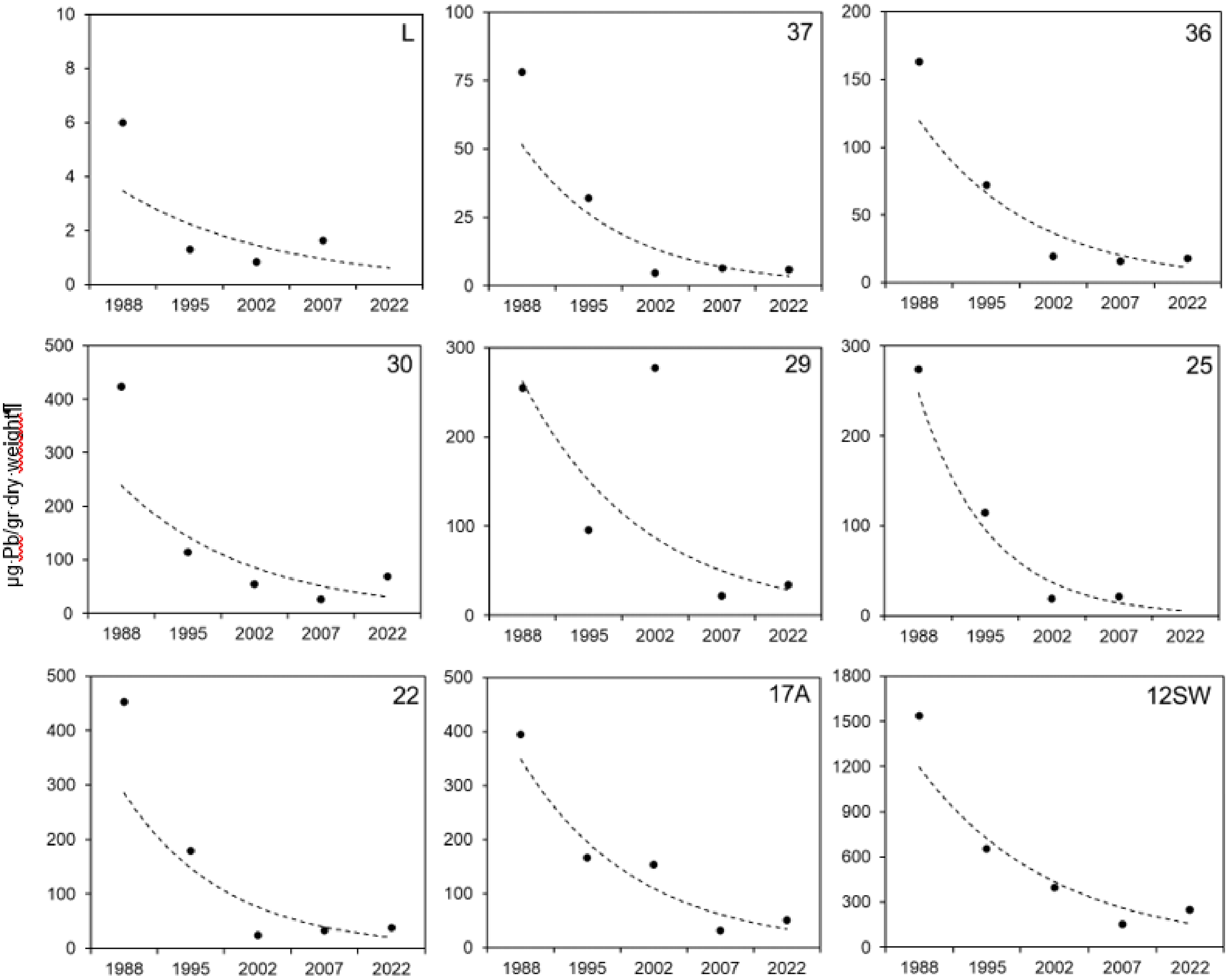


Figure 5. Temporal trend (1988-2022) of Pb (µg/g dry weight) in non-depurated blue mussels across stations in the area of Maarmorilik. For st. L and 25, non-depurated mussels (5 cm) were not included in the analyses of 2022 samples as samples were lost (detailed in chapter 2).

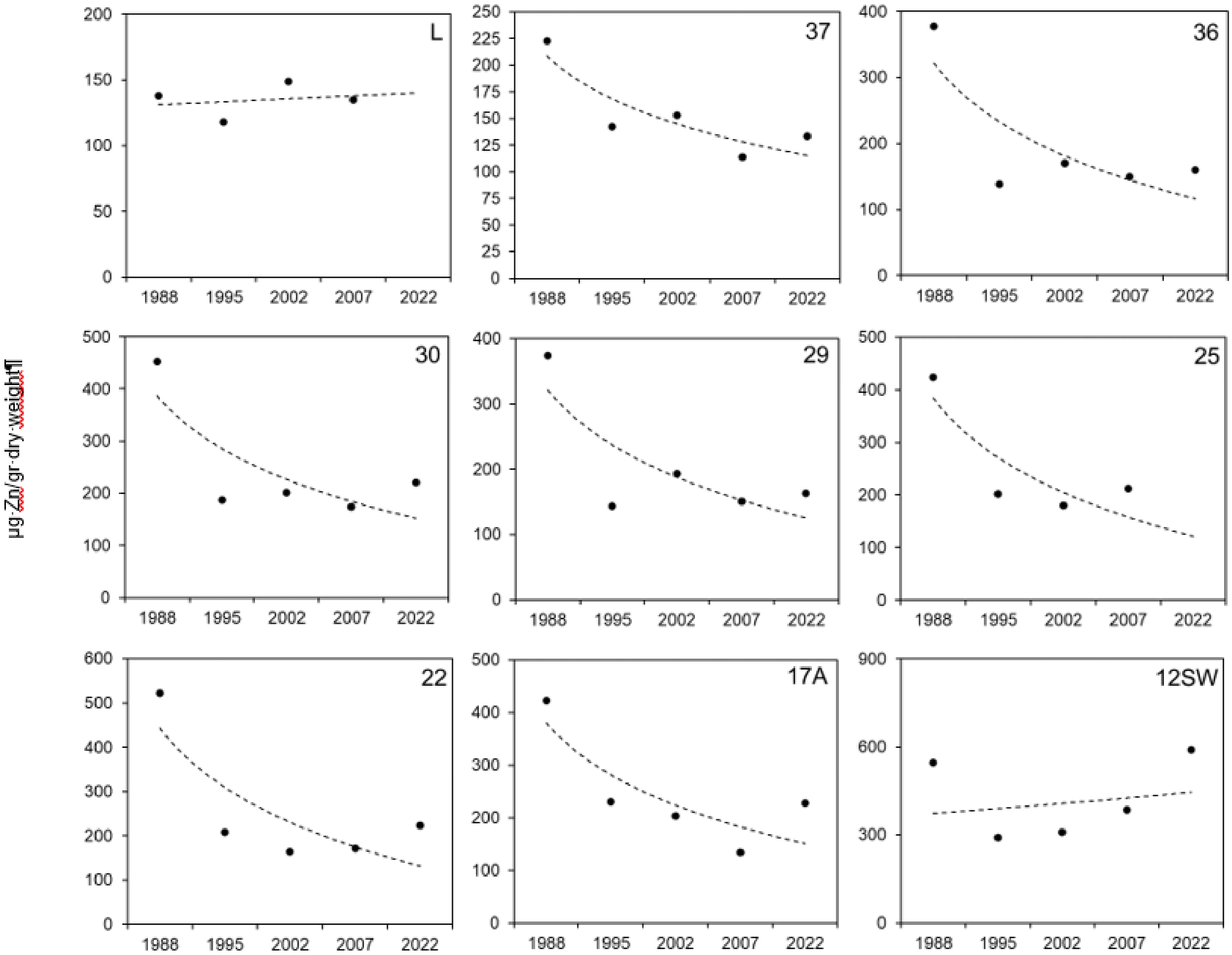


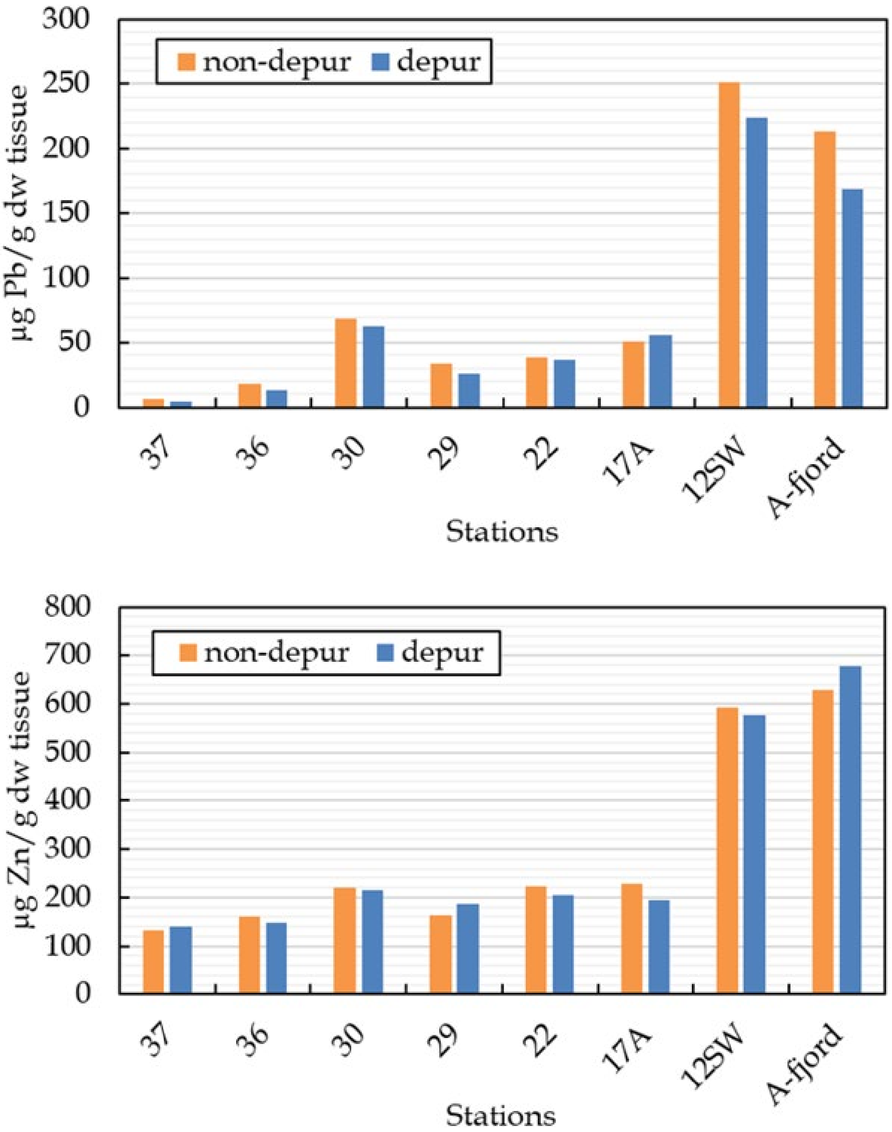
Figure 6. Temporal trend (1988-2022) of Zn (µg/g dry weight) in non-depurated blue mussels across stations in the area of Maarmorilik. For st. L and 25, non-depurated mussels (5 cm) were not included in the analyses of 2022 samples as samples were lost (detailed in chapter 2).

4.2.3 Non-depurated versus depurated mussels

Environmental monitoring has traditionally relied on metal concentrations from non-depurated mussels. However, studies suggest that depurating mussels before chemical analysis could provide more accurate and reliable data by reducing the influence of recently ingested contaminants that have not yet accumulated in the mussel tissues and instead merely reflect the gut content (Chapman, 2016; Robinson et al., 1993).

Figure 7 shows the Pb and Zn concentrations in non-depurated and depurated mussels collected at eight sampling stations. Across all stations except the most polluted stations (12SW and A-fjord), depurated mussels showed rather similar Pb concentrations to non-depurated mussels. At st 12SW and A-fjord, the depuration appeared to have an effect on the Pb concentration as depurated mussels had lower Pb concentration than non-depurated mussels. For Zn, no major differences were observed between depurated and non-depurated mussels except at st A-fjord where the sample of depurated mussels appeared to have slightly higher Zn concentration than non-depurated. Based on the present data, the significance of the depuration practice appears to be inconclusive. Further studies with a higher number of replicates should be included to conclude on the appropriateness of the method.

Figure 7. Pb and Zn concentrations (µg/g dry weight) in samples consisting oof 20 non-depurated or depurated (24 hours) mussels from eight stations in the area of Maarmorilik collected in 2022.

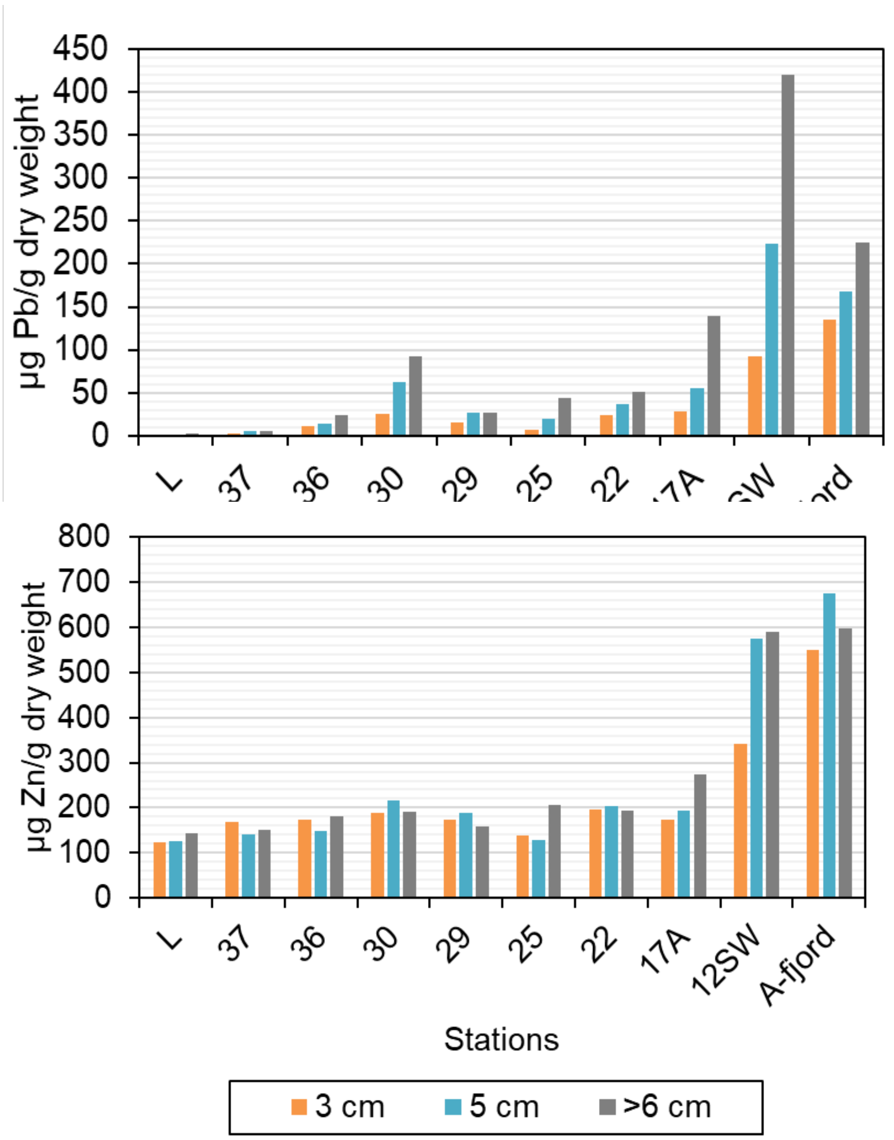


4.2.4 The effect of size on Pb and Zn concentrations in blue mussels

The Pb and Zn concentrations for three size groups of depurated blue mussels (3, 5, and > 6 cm) are presented in Figure 8 to evaluate the influence of mussel size on metal concentrations. Higher Pb concentrations were consistently found in larger mussels across stations. The highest concentrations were observed at st. 12SW, with Pb concentrations ranging from 419.7 µg/g dry weight in the largest mussels (> 6 cm), 223.7 ug/g dry weight in 5 cm sized mussels, and 92.6 µg/g dry weight in the smallest (3 cm). These results aligned with previous monitoring results from 2008 (Schiedek et al., 2009), highlighting that shell length, as a proxy of age, indicates that larger and hence older mussels have been exposed to contaminants for a longer period compared to smaller mussels.

The trend for Zn concentrations in blue mussels across size groups was less consistent (Figure 8). At most stations, the Zn concentration appeared to be independent of size, with similar Zn concentrations observed across size groups. The largest variation was found at st. 12SW, where Zn concentrations ranged from 590.7 µg/g dry weight in the largest mussels (>6 cm) to 342.7 µg/g dry weight in the smallest (3 cm).

Figure 8. Pb (upper) and Zn concentrations (lower) (µg/g dry weight) in depurated blue mussels across three size groups (3, 5, and > 6 cm) across stations in the area of Maarmorilik collected in 2022.



These results demonstrate that the relationship between size and metal accumulation is highly metal-specific. The pronounced increase in Pb concentrations with size reflects the bioaccumulating property of Pb and the inability of the mussels to regulate Pb. Riget et al. (1997) found that two to three years after contamination exposure had ceased, only about half of the accumulated Pb in mussels was eliminated, reflecting that the Pb is very strongly bound in the mussels. In contrast, the similar Zn levels across size groups may be explained by the mussel's ability to regulate Zn uptake and elimination. Since Zn is an essential metal for biological functions, mussels actively manage both its absorption and excretion, maintaining homeostasis even in environments with varying levels of Zn (Rainbow, 2002; Riget et al., 1997).

4.2.5 Guideline values for human consumption

Blue mussels are commonly collected and consumed by locals in Greenland. However, the blue mussels in the fjords near Maarmorilik have previously been evaluated to pose a potential health risk for human consumption due to elevated Pb levels (Johansen et al., 2008; Schiedek et al., 2009). The risk is based on comparisons of the Pb levels in mussels against the established Greenlandic "maximum allowed level" for Pb for retail trade of mussels as dietary items for humans. For mussels, this level is set to 1.5 µg/g wet weight

(Ministeriet for Fødevarer, Landbrug og Fiskeri, Fødevarestyrelsen, 2023) (https://nalunaarutit.gl/-/media/lovfiler/2023/rigslovgivning/bekendt-goerelse-nr-436-af-27042023da.pdf). Given that the mean dry weight percentage in the mussels is 15.4 % (Schiedek et al., 2009), this corresponds to a maximum allowed level of 9.7 µg/g on a dry weight basis.

Despite minor variations in Pb concentrations due to mussel size and depuration methods (Table 3), Pb concentrations in mussel samples at st 12SW, A-fjord, 17A, 22, 25, 29, 30 and 36 exceeded this regulatory level of 9.7 µg/g dry weight. Figure 9 illustrates these findings with red-marked sections of the coastline where Pb concentrations exceeded the level for Pb intake in Greenlandic dietary items. Thus the figure shows that all monitored stations in 2022 in a distance of 12 km from the mine exceeded this level. Similar exceedances were observed in monitoring data from 2008 (Schiedek et al., 2009), indicating persistent contamination in these areas.

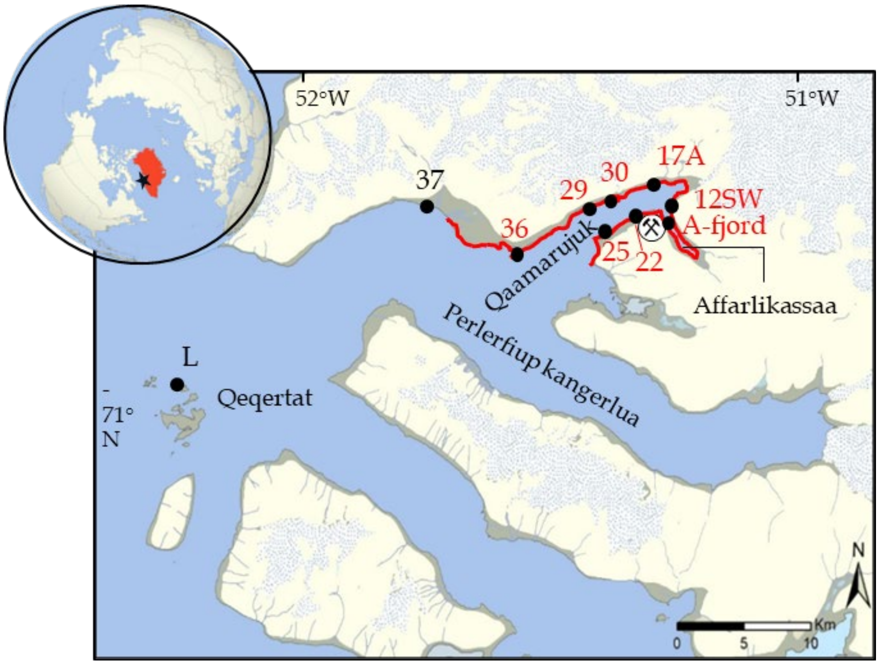
Table 3. Pb concentrations (µg/g dry weight) in non-depurated and depurated (separated in size groups) mussels across stations in the area of Maarmorilik collected in 2022.

Station	**Non-depurated**	**Depurated**		
	5 cm	**3 cm**	**5 cm**	**6 cm**
L	NA	1.52	1.28	1.88
37	6.02	3.00	4.76	5.07
36	17.9	11.0	13.5	24.2
30	68.5	25.5	62.3	91.8
29	34.0	15.8	26.0	26.9
25	NA	7.20	18.9	43.1
22	38.9	24.5	36.7	51.5
17A	50.6	27.5	55.6	139
A-fjord	213.3	136	168	225
12SW	251.5	92.6	224	420

In contrast, Pb concentrations at st. 37 and L, located outside the Qaamarujuk fjord approximately 20 and 37 km from the mine, respectively, pollution sources, remained below the allowed level. Due to the high Pb concentrations observed in large (6 cm) mussels at st. 36 (24.2 µg/g), located 12 km from the mine, the marked area has been extended by extrapolation beyond st. 36. Similarly, due to the very high Pb concentrations observed in large mussels from st. 25 (43.1 µg/g), the marked area has been extended beyond this station. These extensions establish a safety margin of 15 km on the north coastline from the mine, at which mussel Pb concentrations are expected to remain below the allowed level of 9.7 µg/g dry weight.

In contrast to the maximum allowed level for Pb, no Greenlandic Zn level for retail trade of mussels as dietary items for humans intake in dietary items exists.

Figure 9. Sampling stations and area (marked in red) where Pb concentrations in mussels exceeded the recommended threshold for ‘maximum level for intake’ of 9.7 µg/g dry weight.



5 Conclusion

The environmental monitoring data of sediment and blue mussel samples collected in 2022 from Maarmorilik indicates a clear pattern of consistent Pb and Zn contamination in the fjords resulting from historical mining activities. The highest concentrations of Pb and Zn were observed at st. 12SW and A-fjord located near the old waste rock dump site. The concentrations decreased with increasing distance to the mine. The spatial distribution of metal concentrations in both sediments and blue mussels suggests that the primary source of pollution is around the Black Angel Mountain, with waste rock on the mountain slopes and on the coastal seafloor, as well as the old camp area.

Over time, Pb and Zn concentrations in mussels have generally decreased across most stations, reflecting some recovery of the marine environment since the cessation of mining activities in 1990. Overall, the pollution level is similar to the levels found at the last monitoring in 2009. However, notably at st. 12SW, an increase in mussel metal concentrations in 2022 compared to 2007 has been noted, with Zn levels reaching those observed in 1988. This shows ongoing contamination from the residual waste rock deposited on mountain slopes and the coastal sea floor but may also indicate very patchy contamination of the area.

The Pb concentrations in mussels at all monitoring stations in the Affarlikassaa and Qaamarujuk fjords reaching between 12 -15 km from the mine site exceeded the maximum Greenland level for Pb for retail trade of mussels as dietary items for humans.

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ENVIRONMENTAL MONITORING AT THE FORMER LEAD/ZINC MINE MAARMORILIK, NORTHWEST GREENLAND, IN 2022

Metal concentrations in blue mussels (*Mytilus* spp.) in relation to pollution trends and dietary limits

In 2022, environmental monitoring was carried out at the former lead/zinc mine Maarmorilik, Northwest Greenland, which was active during 1973-1990. Samples of sediment and blue mussels were collected and analysed. The study shows there still is an impact from the previous mining operation, and that lead levels exceeds the Greenland regulatory limit for trading mussels as a human dietary items at a distance of ~15 km from the mine site. Overall, the pollution level remains unchanged since last monitoring in 2009.

ISBN: 978-87-7156-937-7
ISSN: 2244-9981