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University of Aarhus · Denmark

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Data sheet

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Abstract: The environmental studies conducted in 2007 show that pollution sources still exist at Maarmorilik 17 years after mine closure in 1990. We can still see elevated lead and zinc levels in the environment. However, over a number of years lead and zinc levels in seawater and biota have decreased, in particular after the mine closed, and the area affected by pollution with lead and zinc has become smaller and smaller over the years. It is now primarily in Affarlikassaa and Qaamarujuk, an impact can be seen.

Keywords: Lead, zinc, mining, Black Angel, Greenland

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Summary

At Maarmorilik in the municipality of Uummannaq lead and zinc ore was mined from 1973 to 1990 by the mining company Greenex A/S. The ore was primarily found in the mountain called "Black Angel". It was mined at an altitude of about 600 metres above sea level and transported in cable cars across the fjord Affarlikassaa to a processing plant in Maarmorilik. Here a lead and a zinc concentrate were produced and loaded on ships, which transported the concentrates to smelters in Europe.

There were a number of sources of pollution while mining took place. Ore crushing and transport of concentrate created dust that was dispersed in the environment. Waste rock dumps with low contents of lead and zinc were also a dust source, but lead and zinc were also released from them to freshwater and the sea. The most important pollutant source, however, was the mine tailings that were discharged into and settled in Affarlikassaa. After mine closure a waste rock dump was excavated and dumped in Affarlikassaa on top of the tailings.

Environmental studies have been conducted at the mine since 1972 by monitoring lead and zinc in seawater, sediments and biota in the fjords at Maarmorilik. Studies of the benthic fauna have also been carried out. This report presents the results of environmental studies conducted in 2007 and assesses the state of the environment in the area. The results are compared with data collected from 1972 to 2005.

The lead and zinc dispersal with dust around Maarmorilik has been monitored by the use of the lichen *Cetraria nivalis*. This species can be used to monitor dispersal of metals in the atmosphere, as it only takes up water, nutrients and contaminants from its surface. In 2007 elevated lead levels in lichens were found in the areas around Affarlikassaa and Qaamarujuk and on the northern coast of Perlerfiup kangerlua, whereas the area affected by zinc was smaller.

The pollution of seawater has changed drastically since mine closure, after which only small amounts of lead have been released from settled tailings and waste rock in the fiord Affarlikassaa. Zinc is still released, but clearly less than when mining took place. In the bottom water of the fiord, the lead concentration was about 1,000 times lower and the zinc concentration about 6 times lower in 2007 than in 1988-89. Lead concentrations in surface waters of Affarlikassaa have remained very low after mine closure and were not elevated in 2007. This is not the case for zinc. In 2005 and 2007 zinc concentrations in surface waters of Affarlikassaa were at the same level as in 1988-89 after having been about 3 times lower in the period from 1995 to 2002.

Brown algae in the tidal zone take up metals from the surrounding water and can be used to monitor seawater pollution. Over the monitoring period, where comparable data exists (1981-2007), both the lead and zinc concentrations have decreased significantly, especially after mine closure and lead levels have decreased more than zinc levels. In 2007 lead con-

centrations were elevated in all of the study area: Affarlikassaa, Qaamarujuk and Perlerfiup kangerlua. Zinc concentrations were elevated in a smaller area: in Affarlikassaa and Qaamarujuk but outside these fjords only on the northern coast of Perlerfiup kangerlua.

Also blue mussels from the tidal zone take up metals from seawater, algae and particles, and are suited to monitor metal pollution. In blue mussels sampled in 2007 lead levels above background are found in Affarlikassaa, Qaamarujuk and Perlerfiup Kangerlua. Elevated zinc concentrations are found in a small area close to Maarmorilik. In previous years the lead concentration in blue mussels was so high, that local people were advised not to collect and eat blue mussels from these fjords. But as the studies in 2005 and 2007 showed that the lead contamination of the blue mussels in the fjords had declined significantly, we now recommend diminishing the area with restrictions to Affarlikassaa, Qaamarujuk and the area just west of here. The lead and zinc concentrations in blue mussels have been declining over a number of years, but lead levels only slowly, because the mussels cannot eliminate all the lead taken up originally.

As one of the most stationary fish species, shorthorn sculpin is used to monitor the metal contamination of fish. In 2007 we found elevated lead concentrations in the livers of sculpins caught at Maarmorilik, but levels have decreased significantly in recent years. In muscle tissue levels are not elevated.

In northern shrimp caught in Qaamarujuk the lead concentration is elevated in 2007. Since 1988, lead concentrations in shrimp have been clearly declining, but most in the beginning of this period.

The elevated lead concentrations found in the fjords at Maarmorilik have been a cause of concern for public health, when people consume fish and other biota, but except for blue mussels as mentioned above, lead concentrations found in 2007 are below guidelines set to protect human health.

The environmental studies conducted in 2007 show that pollution sources still exist at Maarmorilik 17 years after mine closure in 1990. We can still see elevated lead and zinc levels in the environment. However, over a number of years lead and zinc levels in seawater and biota have decreased, in particular after the mine closed, and the area affected by pollution with lead and zinc has become smaller and smaller over the years. It is now primarily in Affarlikassaa and Qaamarujuk, an impact can be seen.

Eqikkaaneq

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Uillut ulittarneranniittartuullutik saffiugassanik, uumasuaqqanik pujoralaasanillu immamiit tigooraasarput taamammallu immap mingutsitaaneranut uuttuutigineqarsinnaasarlutik. Uillut 2007-mi katersukkani Affarlikassaaniittut, Qaamarujummiittut Perlerfiullu Kangerluaniittut qaffasissumik aqerlortaqarput, Maarmorillulli eqqaani annikitsumiittut taamaallaat zinkertaat qaffasilluni. Siusinnerusukkut uillut kangerlunniittut ima aqerlortaqartigisaraluarput nerineqarnissaat inassutigineqartarani. Kisiannili 2005 aamma 2007-mi misissuinertigut mingutsitsinerup qanoq appariarsimatiginera paasineqarmat uillut nerineqannginnissaannik inassutip taamaallaat Affarlikassaanut, Qaamarujummut kiisalu tamatuma kitaanut atuutilernissaa siunnersuutigineqarpoq. Aqerloq zinkilu ukiuni qassiini annikilliartortuarsimapput, aqerlulli annikilliartornera kigaappoq uillut aqerloq tigoorareeraangamikku aniatissinnaanneq ajormassuk.

Kanassut nuttartorsuunnginnamik tamaani aalisakkat mingutsitaanerata malinnaaffigineqarnerani atorneqartarput. 2007-mi kanassut Maarmorillup eqqaani pisat tingui qaffasissumik aqerlortaqarput, ukiunili kingullerni aqerlortaqannginnerulersimaqalutik. Kanassut nerpiisa akui allanit qaffasinnerunngillat.

Raajat itisoormiut 2007-imi Qaamarujummi pisat aqerlortaat qaffasippoq. Aqerlortaqassusiat 1988-imili malunnavissumik appariartorsimavoq, annermilli piffissap tamatuma aallaqqaataani.

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2007-mi misissuinertigut paasineqarpoq Maarmorillup eqqaani suli – aatsitassarsiorfiup 1990-imi uninneraniit ukiut 17-it qaangiunneranni – mingutsitsisoqartoq taamalu avatangiisini aqerlup zinkillu annertuujunerat uuttorneqarsinnaalluni. Ukiulli qassiit ataatsimut isigalugit mingutsitsineq malunnaqisumik appariarsimavoq, pingaartumik aatsitassarsiornerup 1990-imi uninnerata kingorna, aammalu sumiiffiit aqerlumik zinkimillu mingutsitaasimasut annikilliartuinnarlutik. Maanna annermik Affarlikassaata kiisalu Qaamarujuup sunnerneqarsimanerat takuneqarsinnaavoq.

Resume

Ved Maarmorilik i Uummannaq kommune foretog mineselskabet Greenex A/S minedrift efter bly og zink i perioden 1973 til 1990. Bly- og zinkmalmen fandtes hovedsagelig i fjeldet kaldet Sorte Engel. Her blev malmen brudt i ca. 600 meters højde og transporteret i en tovbane over fjorden Affarlikassaa til et oparbejdningsanlæg i Maarmorilik. Der blev produceret et bly- og zinkkoncentrat, som blev lastet på skibe og transporteret til metalsmelteværker i Europa.

Mens minedriften fandt sted, var der en række forureningskilder. Malmknusning og transport af koncentrat producerede støv, som blev spredt i omgivelserne. Såkaldte gråbjergsdumpe med et lavt indhold af bly og zink var også en støvkilde, men de frigav også bly og zink til ferskvand og havet. Den største forureningskilde var dog resterne fra oparbejdningen, såkaldt ”tailings”, som blev udledt til Affarlikassaa, hvor de aflejredes på bunden. Efter lukningen af minen blev en gråbjergsdump gravet op og placeret på bunden af Affarlikassaa ovenpå ”tailings”.

Miljøtilstanden i fjordene ved Maarmorilik er blevet undersøgt siden 1972 ved at analysere for bly og zink i indsamlede prøver af havvand, sedimenter, planter og dyr. Der er også foretaget undersøgelser af bundfaunaen. Denne rapport præsenterer resultaterne af de undersøgelser, som blev udført i 2007 og vurderer den nuværende miljøtilstand i området. Resultaterne sammenlignes med data fra tidligere år.

Spredning af bly og zink med støv fra minevirksomheden er undersøgt ved at indsamle og analysere lavarten snekruslav i området ved Maarmorilik for bly og zink. Denne art kan bruges til at måle støv-nedfald, da den udelukkende optager næring fra luften gennem sin overflade. I 2007 var der forhøjet blyindhold i transplanteret lav i Affarlikassaa og Qaamarujuk og på nordkysten af Perlerfiup kangerlua, mens det påvirkede område for zink var mindre.

Forureningen af havvandet er formindsket markant efter minevirksomhedens ophør. Der afgives nu kun små mængder bly fra deponeret “tailings” og gråbjerg på bunden af Affarlikassaa, mens der stadig frigøres zink, dog tydeligt mindre end mens minedriften fandt sted. Blyindholdet i fjordens bundvand var i 2007 ca. 1000 gange lavere og zinkindholdet ca. 6 gange lavere end i 1988-1989. Blyindholdet i over-fladevandet har været lavt siden minens lukning og var i 2007 ikke forhøjet. Derimod var zinkindholdet i overfladevandet i både 2005 og 2007 på samme niveau som i 1988-89, efter at de i perioden fra 1995 til 2002 havde været ca. 3 gange lavere.

Brunalger, som vokser i tidevandszonen, optager metaller fra det omgivende vand og kan derfor anvendes til at måle forureningen af havvandet. Set over hele overvågningsperioden (1981-2005) er både bly- og zinkkoncentrationen i tang faldet, specielt efter minens lukning, og blykoncentrationen er faldet mere end zinkkoncentrationen. I 2007 var der forhøjede blyværdier i hele det undersøgte område: i Affarlikassaa, i Qaamarujuk og i Perlerfiup kangerlua. Zinkværdierne var forhøjet i et

mindre område: i Affarlikassaa and Qaamarujuk, men udenfor disse fjorde kun på den nordlige kyst af Perlerfiup kangerlua.

Blåmuslinger i tidevandszonen optager metaller fra havvand, alger og partikler, og kan derfor også bruges til måle forureningen af havvandet. I blåmuslinger indsamlet i 2007 er der forhøjede værdier af bly i fjordene Affarlikassaa, Qaamarujuk og Perlerfiup kangerlua, mens der kun er forhøjede zinkværdier i et mindre område ved Maarmorilik. Tidligere var blyindholdet i muslingerne så højt, at det blev frarådet at spise blåmuslinger fra fjordene. Men da undersøgelserne i 2005 og 2007 har vist, at forureningen er faldet væsentligt, foreslås dette område indskrænket til Affarlikassaa, Qaamarujuk og området umiddelbart vest herfor. Bly- og zinkværdierne har været faldende over en årrække, men det er gået langsomt for bly, fordi muslingerne ikke kan udskille alt det bly, de én gang har optaget.

Almindelig ulk anvendes til at overvåge forureningen af fisk i området, da den er ret stationær. I 2007 fandtes forhøjede blyværdier i lever fra ulk fanget ved Maarmorilik, men niveauet er faldet væsentligt i de seneste år. I kød fra ulke er der ikke forhøjede værdier.

I dybhavsrejer fanget i Qaamarujuk fandtes forhøjede blyværdier i 2007. Niveauet har været tydeligt faldende siden 1988, men mest i begyndelsen af perioden.

De forhøjede blyværdier, der er fundet i fjordene ved Maarmorilik, har givet anledning til bekymring hos mennesker, som spiser fisk og andre produkter fra området. Ved undersøgelserne i 2007 er blyindholdet under gældende grænseværdier, bortset fra blåmuslinger i området nævnt ovenfor.

Undersøgelserne i 2007 viser, at der i Maarmorilik-området fortsat – 17 år efter minedriftens ophør i 1990 - findes forureningskilder, som bevirker, at der kan måles forhøjede bly- og zinkniveauer i miljøet. Set over flere år har forureningsniveauet dog som helhed været markant faldende, især efter minevirksomhedens ophør i 1990, og de områder, som er bly- og zinkforurenede, er efterhånden blevet mindre og mindre. Det er nu primært kun i Afffarlikassaa og Qaamarujuk, der kan spores en påvirkning.

1 Introduction

Zinc and lead ore was mined in the period 1973 to 1990 at Maarmorilik in Northwest Greenland. Maarmorilik is located in the inner part of a large fjord system. The closest community is Ukkussissat about 25 km to the west and the main town Uummannaq is about 80 km from Maarmorilik (Figure 1.1).

The ore was primarily mined in the "Black Angel" mountain at about 600 meters altitude and transported with cable cars across the fjord Affarlikassaa to a flotation plant in Maarmorilik. Here zinc and lead concentrates were produced, loaded into ships and transported to European smelting plants. The company Greenex A/S operated the mine.

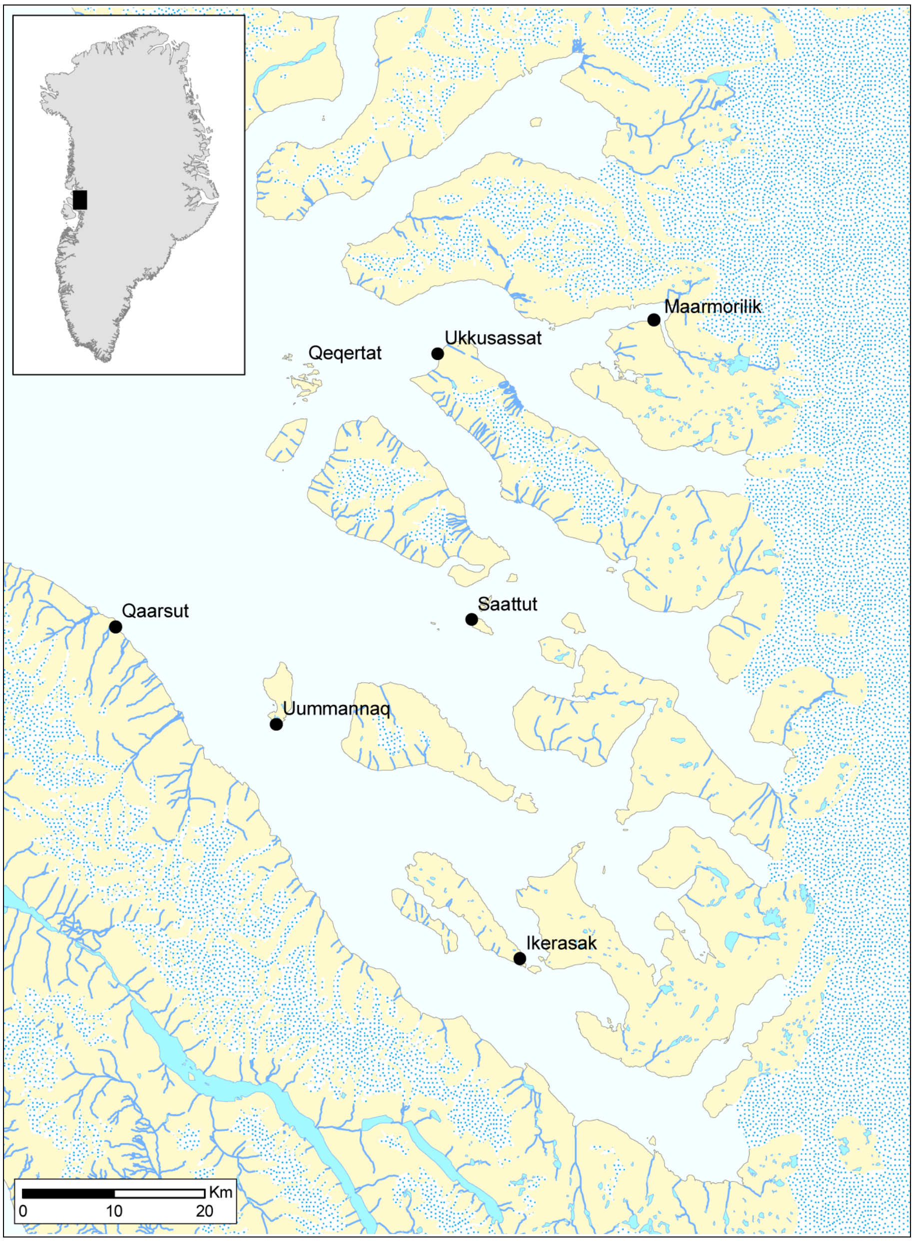


Figure 1.1. Location of Maarmorilik, nearby settlements and the islands Qeqertat.

After flotation the tailings were discharged into the fjord Affarlikassaa, where they settled. During mining this discharge caused annual dissolution of several tons of lead and zinc in the fjord, leading to a serious pollution of the marine environment. A second pollution source was dust dispersal created by ore crushing and handling of concentrates. A third important source was waste rock left on the steep slopes of the mountains. These waste rock dumps contained several hundred thousand tons of rock and had elevated concentrations of lead and zinc. One of these dumps, "The Old Waste Rock Dump" was particularly polluting the sea with lead and zinc. In the summer of 1990 this dump was removed to the extent possible and most of it dumped in Affarlikassaa on top of the tailings.

The pollution in the area was monitored while mining took place and has continued after mine closure. It comprises regular sampling and chemical analysis of seawater, seaweed, mussels, fish, prawns and lichens and with longer intervals marine sediments. Studies of benthic fauna composition have also been conducted with intervals of several years. This report presents results from field work carried out in 2007, and the data are compared with results from previous years. The most recent monitoring was published by Johansen et al. (2006).

2 Sampling

Sampling was carried out in the period 23 to 28 August from the research vessel Adolf Jensen. Gert Asmund, Sigga Joensen and Jan Damgaard Nielsen from NERI carried out the field work together with the ship's crew.

Samples of lichens (*Cetraria nivalis*) were collected at 23 stations in Affarlikassaa, Qaamarujuk and Perlerfiup Kangerlua and on the islands Qeqertat and Saatut (cf. section 4.1, Figure 1.1, Figure 2.1 and 2.2 and Annex I). Only fresh living lichens growing on death organic matter was collected in order to ensure that the lichens would only be able to accumulate metals from the air and not underlying rocks. Samples were kept in paper bags.

Seawater samples were collected at stations 1 and 3 Affarlikassaa and at a reference station at Uummannaq (cf. section 4.2, Figure 1.1, Figure 2.1 and 2.2 and Annex II). Water samples were collected with a reversible Hydrobios water sampler, filtered trough a 0.45 µm polycarbonate filter, and added 1 ml suprapure nitric acid per litre.

Growing tips of seaweed (*Fucus vesiculosus* or *Fucus distichus*) were collected at 27 stations in Affarlikassaa, Qaamarujuk, Perlerfiup Kangerlua and at Qeqertat (cf. section 4.3, Figure 1.1, Figure 2.1 og 2.2 and Annex III). Samples were rinsed 3 times in demineralised water and frozen in polyethylene bags. At each station 2 samples of seaweed were collected at 10 to 30 metres distance for statistical reasons in order to account for local variation. In subsequent presentation and calculation we have used the geometric mean concentration.

Blue mussels (*Mytilus edulis*) were collected at 22 stations in Affarlikassaa, Qaamarujuk, Perlerfiup Kangerlua and at Qeqertat (cf. section 4.4, Figure 1.1, Figure 2.1 and 2.2 and Annex IV). Blue mussels collected at each station were divided into size classes according to their shell length. The objective was to pool 20 smaller mussels (shell length 5-6 cm) as one size group and 20 larger mussels (shell length 6-7 cm) as another. The adductors of the mussels were cut and the mussels were allowed to drain, before the soft parts of the mussel were cut out of the shell with a stainless steel scalpel. The soft parts of each size group were then frozen.

Shorthorn sculpin (*Myoxocephalus scorpius*) was caught in three areas, in the inner part of Qaamarujuk, in the outer part of this fjord and at a reference site at Qeqertat (cf. section 4.5, Figure 1.1, Figure 2.1 and Annex V). Sex, length and weight of the fish were recorded. Liver and muscle samples for lead analyses were frozen in polyethylene bags.

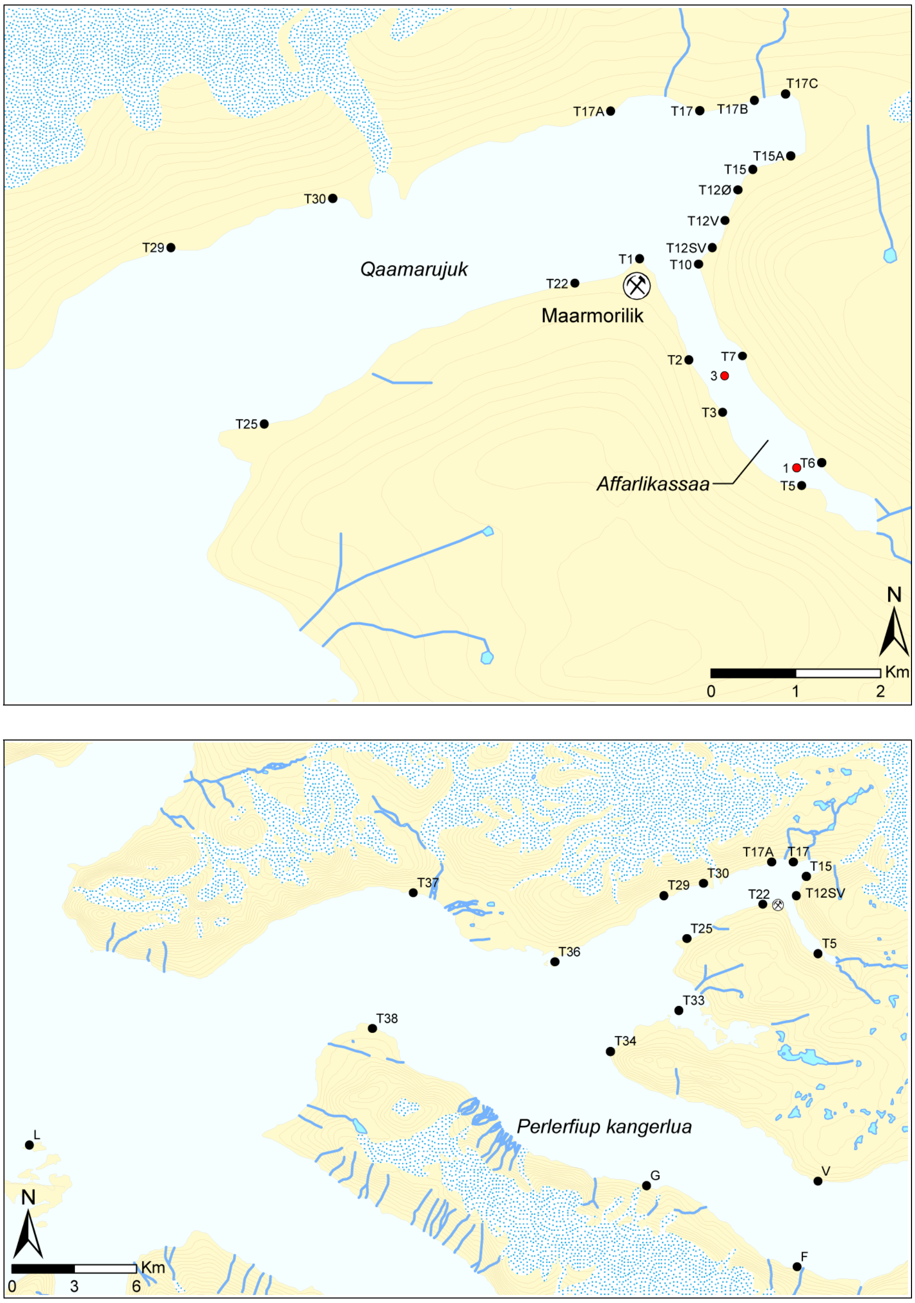


Figure 2.1. Sampling stations close to Maarmorilik (above) and further away (below). Figures alone denote sampling stations for seawater. Letters with or without figures denote sampling stations for lichens, seaweed and blue mussels.

Northern shrimp (*Pandalus borealis*) was caught in three areas, in the inner part of Qaamarujuk, in the outer part of this fjord and at a reference site at Qeqertat (cf. section 4.6, Figure 1.1, Figure 2.1 and Annex VI). The prawns were caught in baited crab pots fitted with a fine mesh. The prawns were divided into length groups, and of each group the prawns were divided into two samples, one consisting of the meat and the other of the remaining parts (heads and shells). Samples were frozen in plastic bags.

3 Analytical methods and quality control

3.1 Seawater

Seawater was collected by a 2 litre Hydrobios reversible plastic water sampler and stored in 250 ml polyethylene bottles. At the arrival at the laboratory the samples were conserved with 0.25 ml concentrated suprapure nitric acid.

The analyses ware performed by an ICP-MS after online collection and desorbing on a Chelex ion exchanger. Before analyses the pH of the sample to be analysed was adjusted to 4.5 by addition of ammonium acetate.

3.2 Biological samples

At the laboratory of the Department of Arctic Environment at NERI (NERI-DAE), the samples of seaweed, mussels and prawns were initially freeze-dried and then ground in an agate mortar. The dry weight was determined by weighing before and after freeze-drying.

The lichen samples were sorted in the laboratory and all foreign material removed. They were subsequently dried at 60ºC for 24 hours.

A sub sample of c. 1 g of liver or muscle from the fish was cut with a stainless steel blade, so that all surfaces were fresh cut in order to avoid contamination from the exposed parts of the whole sample. Cutting took place on a plastic carving board, while the samples were still partly frozen, using plastic pincers. The dry weight was determined by weighing 2-3 g in porcelain crucible and drying at 105ºC until constant weight.

A 0.3 g sub sample of a dried sample or a 1 g fresh fish sample was then dissolved with 4 ml Merck suprapure nitric acid in Teflon bombs under pressure in an Anton Paar Multiwawe 3000 Microwave Oven. After destruction the samples were transferred to polyethylene bottles with demineralised water (milliQ water) and lead and zinc were measured directly in these solutions. Zinc concentrations were determined using flame AAS (Perkin Elmer AAnalyst 300) and lead concentrations were determined using graphite furnace AAS (Perkin Elmer AAnalyst 800).

3.3 Detection limits

The detection limit for a method is the concentration below which it is not possible to obtain a result that has a sufficiently low uncertainty. The detection limit depends on the method used, the pre-treatment and the dilutions of the samples. The definition of detection limit in this report is the concentration that gives an analytical signal that is 3 times the standard deviation of the blind value.

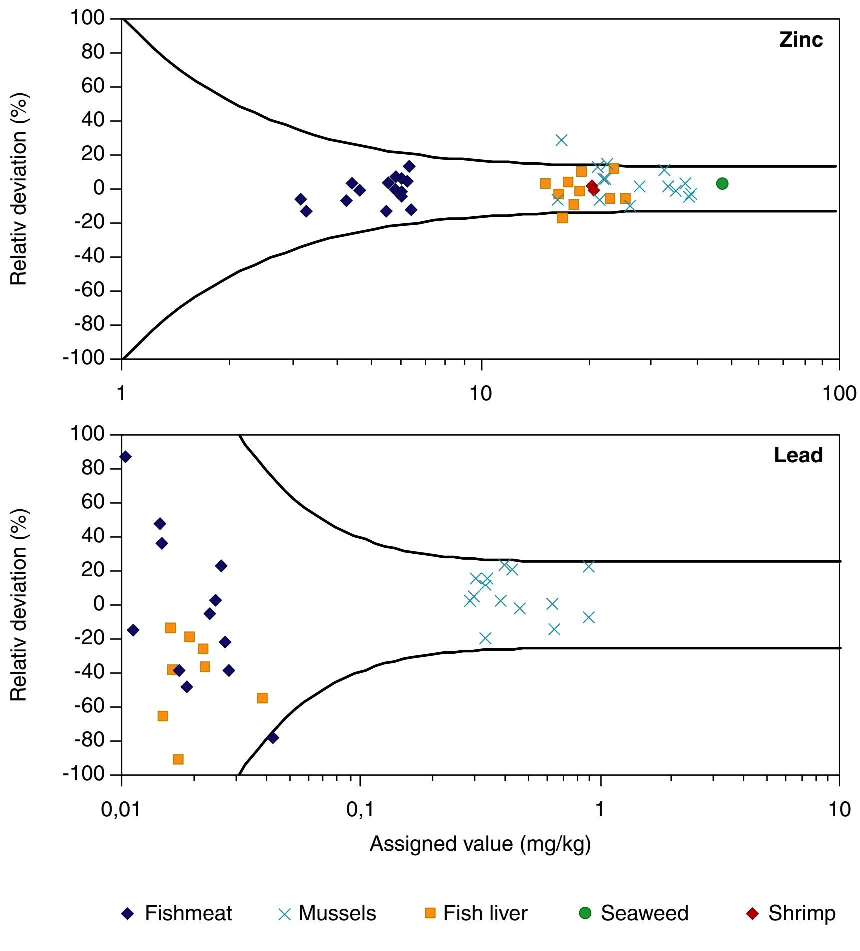
The detection limits for the methods used here are 0.0015 µg/kg for lead and 0.007 µg/kg for zinc in seawater. In biological samples the detection limits are 0.02 µg/g dry matter for lead and 0.8 µg/g dry matter for zinc.

3.4 Quality control

The analytical methods were checked by regularly analyzing certified reference materials Dorm-1, Dolt-3 and Tort-2.

The analytical methods were also checked independently, because NERI-DAE participates in the intercalibration program QUASIMEME organized by the European Union. In this program a sample with an unknown concentration of e.g. lead and zinc is analyzed by many laboratories. Based on the results, the organizers of QUASIMEME compute a so called "assigned value" for the concentration of – in this case – lead and zinc in the sample. Figure 3.1 shows the result of the NERI-DAE's participation in QUASIMEME. In the figure, NERI-DAE's results are shown as the relative deviation from the "assigned value" plotted against the concentration.

Figure 3.1. Results for zinc (above) and lead (below) from NERI-DAE's participation in the QUASIMEME laboratory study programme.



It is seen that for lead the uncertainty by NERI-DAE is about 25% for samples with concentrations higher than 0.05 µg/g wet weight. For biological samples with concentrations lower than 0.02 µg/g wet weight, QUASIMEME only designated so called “indicative assigned values”. In these cases, NERI-DAE found lower concentrations than the “indicative assigned values”. For zinc the uncertainty by NERI-DAE is in almost all cases within 12.5% (Figure 3.1).

The quality of seawater analyses was checked by analysing several QUASIMEME intercalibration samples. In Figure 3.2 and 3.3 the results are compared with the assigned values given by QUASIMEME. It is seen that there is an excellent agreement between the analytical results and the assigned values.

Figure 3.2. Comparison of analytical results with assigned values for zinc, µg/L.

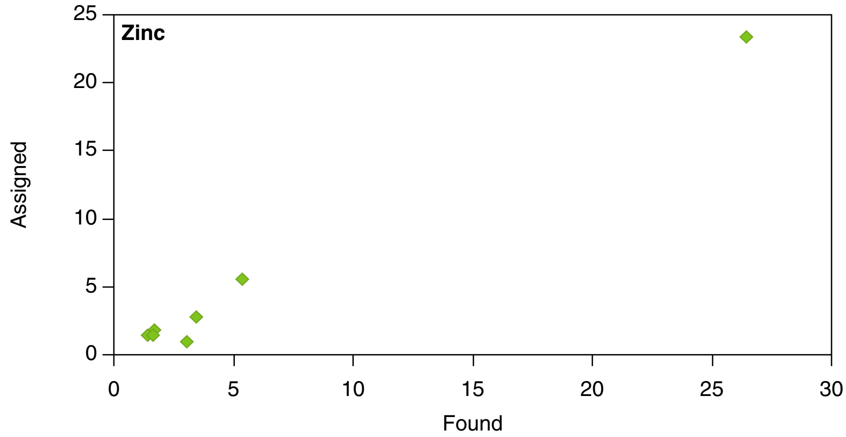
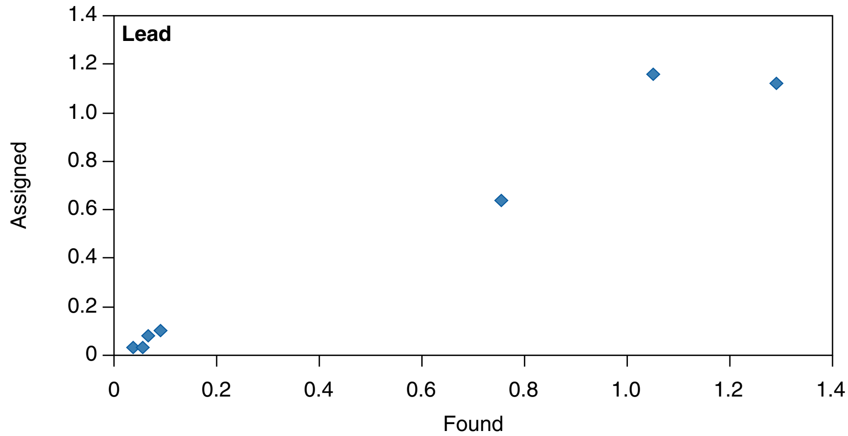


Figure 3.3. Comparison of analytical results with assigned values for lead, µg/L.



Finally the analytical methods were checked by analyzing the same sample twice (same ID# but different nitric acid digestions). In this study, 10 samples were analyzed twice for zinc and 17 samples for lead. The relative deviation was 27% for lead and 3% for zinc. The high relative deviation for lead is caused by a few samples having low lead concentrations, making the lead analysis more uncertain (cf. Figure 3.1). When a sample has been analyzed twice, we have used the average in further calculations.

4 Results and discussion

In this section we present the results of the analyses of lichens, seawater, seaweed, mussels, fish and prawns.

4.1 Lichens

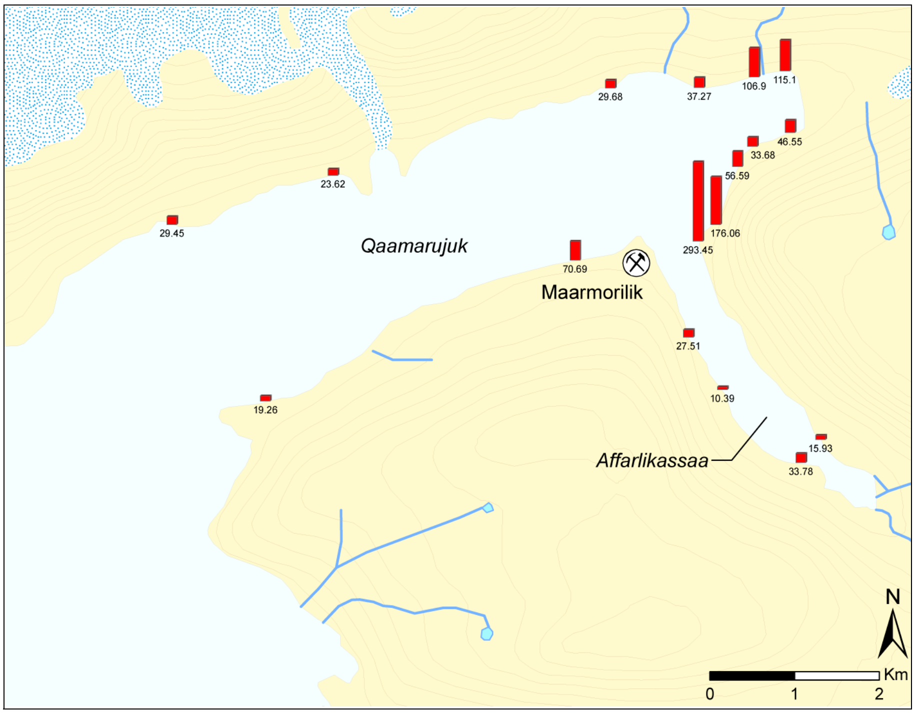
The lichen species *Cetraria nivalis* is common in Greenland and may be used as an indicator of metal pollution of the atmosphere. It grows primarily on dead organic matter and takes up nutrients (and contaminants) exclusively from its surface. We have used it for a number of years to monitor the dispersal of metals through the atmosphere by sampling it at a number of stations close to Maarmorilik and in the region to the west of here. Once accumulated in the lichens metals are only released from the plants at a very slow rate – if at all. Therefore, in order to monitor year to year variation of the air quality we have introduced a method of transplanting lichens from an area unaffected by the pollution at Maarmorilik. However, in 2007 only resident lichens and no transplants were collected, because there was no field work done in 2006. Samples were analyzed for lead and zinc. The results are shown in Annex 1 and the spatial trends illustrated in Figures 4.1 – 4.2.

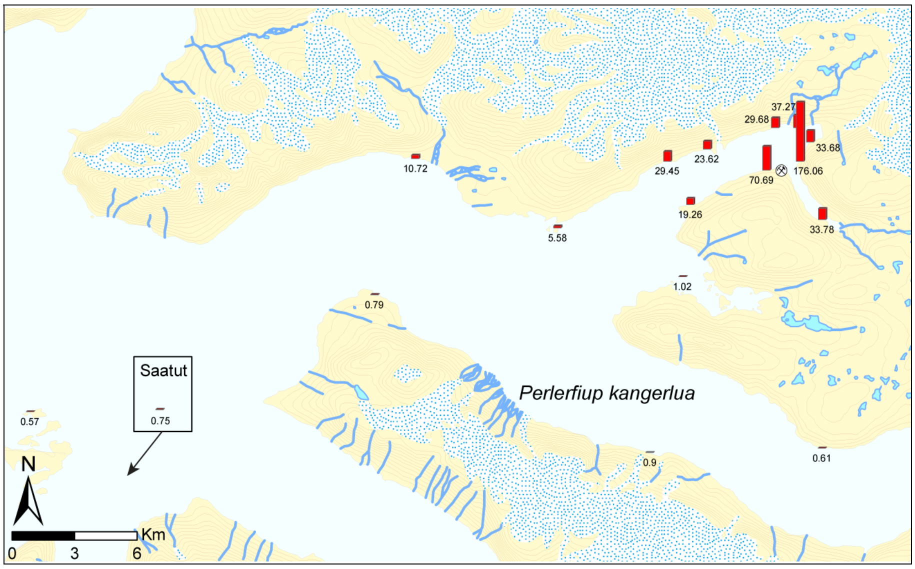
In order to assess the impact of mining activities in Greenland, we have collected lichen samples in areas unaffected by the local sources at the mines. In these reference sites, used to the monitor the impact of mining activities at Nalunaq, Seqi and Maarmorilik, we have found 0.3-1 µg/g lead and 9-18 µg/g in *Cetraria nivalis* (Glahder 2008, Asmund 2008, Johansen et al. 2006).

Compared to these levels, lead concentrations in resident lichens are elevated in Affarlikassaa, Qaamarujuk and the northern coast of Perlerfiup kangerlua, but not in the inner and southern part of this fjord (Figure 4.1). Concentrations are elevated by a factor of up to about 500. The highest concentrations are found below the Black Angel Mountain and at the old waste rock dump and quite high concentrations also on the northern coast of Qaamarujuk, particular in the inner part, and close to Maarmorilik. In inner Affarlikassaa levels are also elevated by 10-30 times. Zinc concentrations show a similar pattern, although the area affected is smaller, and they are not elevated to such a high level as lead, only up to a factor of about 10 (Figure 4.2).

This pattern indicates that the main source of dust dispersal is the waste rock dumps and the remains of these left on the slopes of the Black Angel Mountain. The Maarmorilik area itself also appears to be a source.

Figure 4.1. Lead concentration (µg/g dry weight) in lichen (*Cetraria nivalis*) from sampling stations close to Maarmorilik (above) and further away (below). The location of Saatut is shown in Figure 1.1.





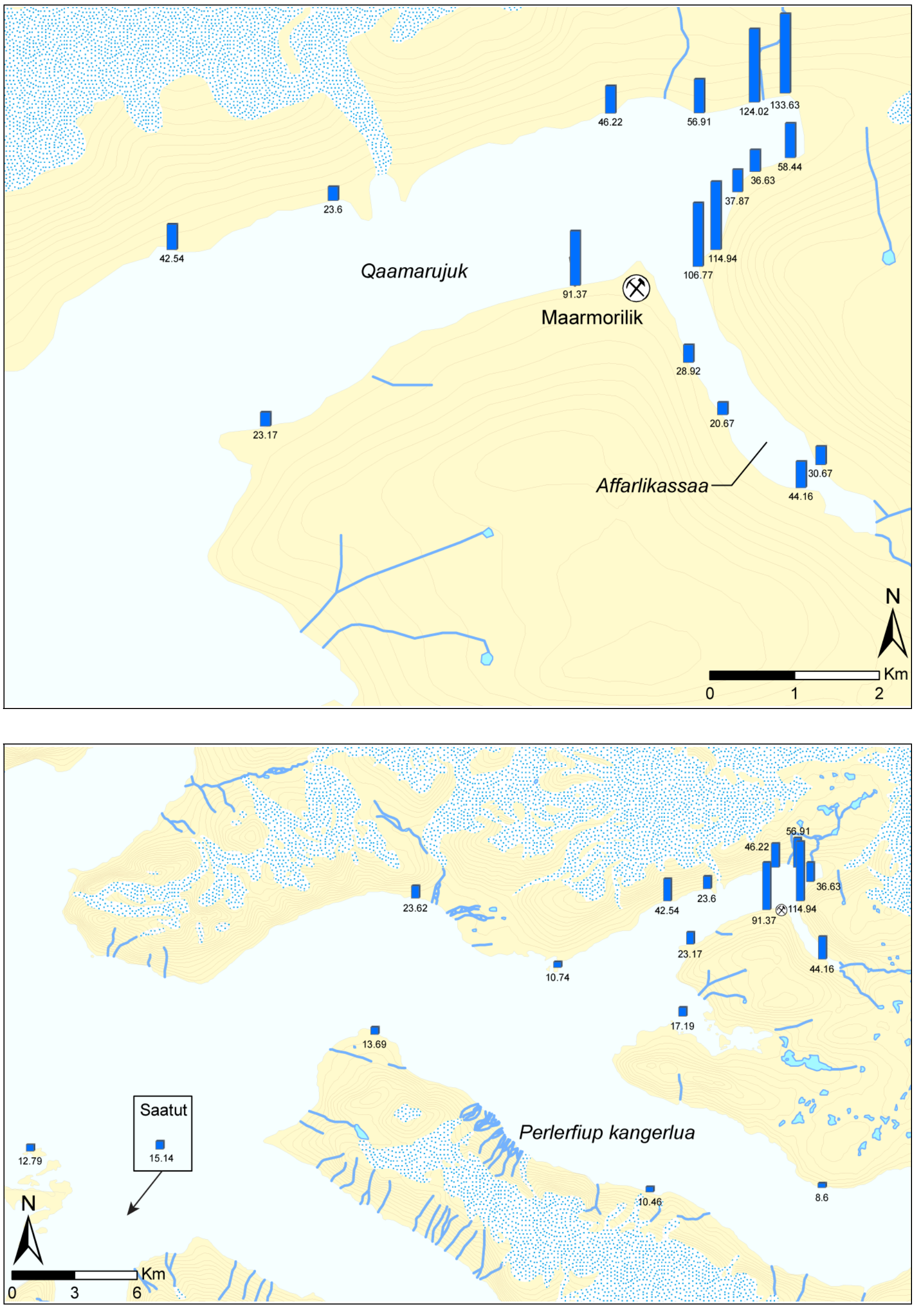


Figure 4.2. Zinc concentration (µg/g dry weight) in lichen (*Cetraria nivalis*) from sampling stations close to Maarmorilik (above) and further away (below). The location of Saatut is shown in Figure 1.1.

4.2 Seawater

While the mine was operating seawater samples were regularly collected in Affarlikassaa and Qaamarujuk and analyzed for lead and zinc. Tailings were discharged at c. 30 meters water depth into Affarlikassaa, and because some lead and zinc dissolved, the bottom water mass of Affarlikassaa (from c. 30 meters to the seafloor at up to 70 meters) was heavily polluted. From this water mass the lead and zinc pollution spread into the neighboring fjords. This happened especially during winter, when the upper and lower water masses in the fjord were mixed.

Today, several years after mine closure in 1990, the pollution of Affarlikassaa has declined dramatically and is controlled by the dissolution rate of metals from tailings and waste rock on the seafloor and other sources on land or in the inter tidal zone. Tailings and waste rock deposited on the sea floor of Affarlikassaa will gradually be covered by sand and silt entering the fjord with river water at the head of the fjord

4.2.1 Spatial trends

At a study conducted in 1995 the pollution of the seawater outside Affarlikassaa was so low that it was difficult to measure. Later studies of seawater therefore have been carried out in Affarlikassaa only and at a reference station. Here we report the results from sampling carried out 25 and 27 August at two stations in Affarlikassaa and at a reference station near Uummannaq. The results are shown in Annex 2 and illustrated in Figures 4.3 and 4.4. There is no indication that cobalt, nickel and copper levels are elevated in seawater, whereas this is the case for lead, zinc and cadmium.

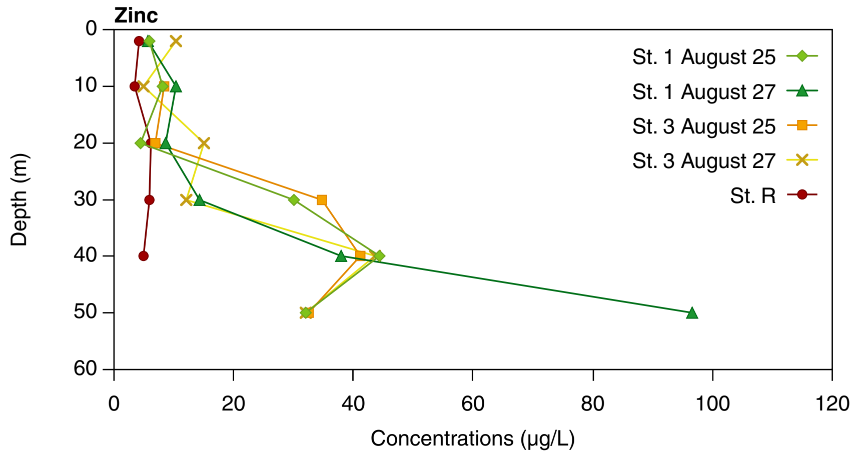


Figure 4.3. Zinc concentrations in Affarlikassaa depicted against water depth µg/L.

In Figure 4.3 the zinc concentration is depicted against water depth. Møller (1984) showed that Affarlikassaa during summer has a pycnocline at about 25 metres water depth, which is the depth of the sill at the mouth of the fjord. This pycnocline divides the fjord into two water masses: a deeper cold and saline water mass and an upper "warm" and less saline water mass. In the upper water mass above sill depth zinc and cadmium concentrations are not elevated, whereas this clearly is the case in deeper water of the fjord.

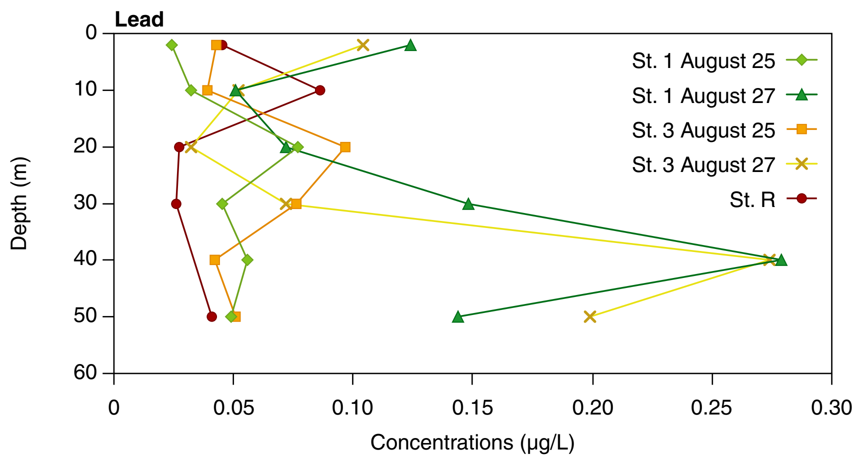


Figure 4.4. Lead concentrations in Affarlikassaa depicted against water depth µg/L.

Figure 4.4 shows the lead concentration depicted against water depth. On 25 August the lead concentration does not appear elevated, whereas on August 27 levels are higher in the deepest water.

This shows that tailings and waste rock deposited on the seafloor in Affarlikassaa is still releasing zinc, and in some cases also lead. This has also been found in earlier studies after mine closure. However levels are much lower than during mining (see below).

4.2.2 Time trends

While mining took place, seawater below the pycnocline was heavily polluted by lead and zinc during summer and fall, while lead and zinc concentrations were much lower above the pycnocline. In Table 4.1 we have computed the mean concentration of lead and zinc in bottom water (30-60 m) and surface water (0-20 m). Concentrations are corrected by subtracting the mean concentration found at the reference station in the Uummannaq region far from Maarmorilik the same year. Thus the concentrations represent the pollution contribution from the mining operation. The coefficient of variation, vZn and vPb, was computed as the standard deviation of the mean divided by the mean.

Table 4.1. Zinc and lead concentration and coefficient of variation (vZn, vPb) in bottom and surface water of Affarlikassaa during fall, corrected for baseline concentrations (from the reference site, see text).

Year	Bottom water				Surface water			
	Zn	vZn	Pb	vPb	Zn	vZn	Pb	vPb
1975	366	0.41	248	0.35	9.29	0.33	8.0	0.44
1976	581	0.25	440	0.24	5.98	0.16	3.9	0.12
1977	480	0.15	359	0.13	14.5	0.41	4.6	0.38
1978	788	0.28	180	0.42	11.2	0.33	1.6	0.60
1979	293	0.12	140	0.095	8.29	0.20	0.74	0.26
1980	270	0.23	117	0.25	7.94	0.42	1.03	0.98
1981	104	0.12	116	0.19	4.41	0.29	11.1	0.47
1982	105	0.06	82	0.12	2.55	0.38	3.7	0.28
1983	200	0.23	74	0.21	5.83	0.44	2.87	0.31
1984	345	0.05	154	0.074	3.85	0.27	0.88	0.20
1985	199	0.07	109	0.081	3.84	0.20	2.78	0.27
1986	234	0.06	82	0.12	6.75	0.18	2.59	0.20
1987	297	0.09	253	0.21	1.70	0.78	3.41	0.29
1988	211	0.04	255	0.066	1.32	1.90	2.93	0.33
1989	138	0.05	231	0.039	3.57	0.38	2.35	0.54
1990	256	0.06	93	0.083	10.37	0.23	6.8	0.092
1991	82	0.06	2.7	0.043	3.67	0.24	0.49	0.15
1992	42	0.07	2.5	0.11	3.90	0.22	0.40	0.090
1993	50	0.16	0.44	0.11	3.22	0.44	0.12	0.21
1994	103	0.21	1.24	0.16	2.05	0.21	0.13	0.13
1995	26	0.10	0.208	0.14	1.03	0.34	0.12	0.20
1996	18	0.14	0.166	0.20	0.15	3.14	0.086	0.28
1998	36	0.06	0.207	0.21	0.89	0.36	0.069	0.16
2000	12.2	0.09	0.225	0.293	0.655	0.687	-0.036	-1.61
2002	14.4	0.10	0.181	0.123	0.893	0.226	0.040	0.411
2005	21.05	0.40	0.11	0.91	2.17	0.79	0.06	1.42
2007	32.2	0.20	0.09	0.32	3.5	0.39	0.01	2.4

The results for the bottom water are shown in Figure 4.5. Already at the study in 1990, shortly after production stopped, lead levels had declined compared to the three previous years, while zinc concentrations had increased, probably because of waste rock dumping. This dumping was known to release twelve times as much zinc as lead (Asmund 1992). It is striking that the lead concentration has decreased drastically after mine closure in 1990, about 1000 times lower in the period 1995 to 2007 than in 1988-1989. The zinc concentration in 2007 is only about 6 times lower than in 1988-1989, and in the past 12 years levels have not decreased further. Thus zinc is still released from the sediments in Affarlikassaa, and this probably will continue for decades.

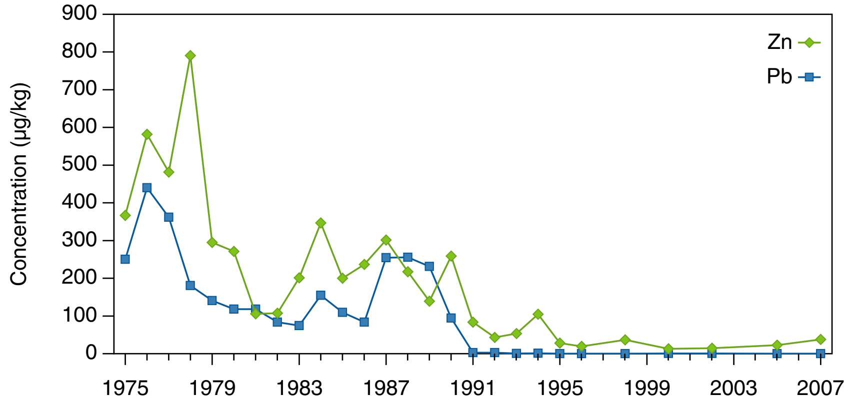


Figure 4.5. Lead and zinc concentrations in bottom water of Affarlikassaa. µg/L.

The results for the surface water are shown in Figure 4.6. While mining took place, the lead and zinc pollution of the surface water in Affarlikassaa was primarily caused by mixing with the heavily polluted bottom water during winter and spring.

In 1990 the removing and dumping of The Old Waste Rock Dump was a significant source of zinc pollution of the surface water. In 1990 also the lead concentrations were high, probably because there was a high content of lead in the mine tailings due to flotation of old oxidized ore.

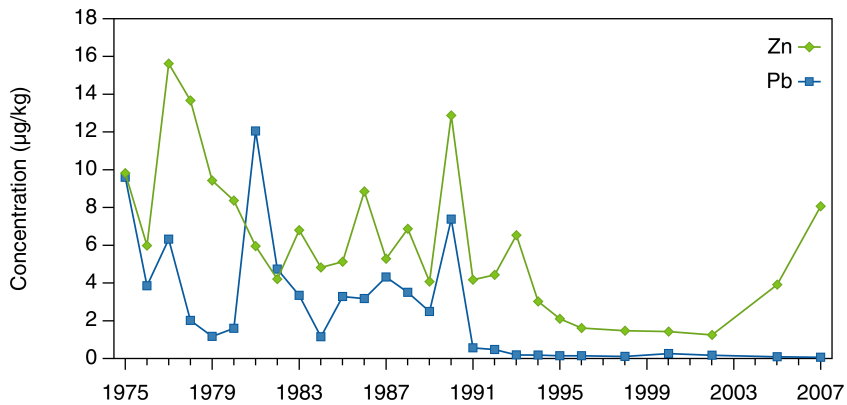


Figure 4.6. Lead and zinc concentrations in surface water of Affarlikassaa. µg/L.

Figure 4.6 shows that the lead concentration in the surface water has remained low after mine closure, and in 2007 it was not elevated. On the other hand zinc concentrations have only declined slightly after mine closure, and in 2007 the concentration was higher than seen since 1992. This could indicate that zinc enters from land sources (probably primarily waste rock dumps). Another possibility is reduced water exchange between Qaamarujuk and Affarlikassaa in the periods where levels in Affarlikassaa are high.

In Table 4.2 we have calculated the ratio between dissolved lead and zinc in the bottom and surface water of Affarlikassaa. Concentrations are corrected by subtracting the mean concentration found at the reference station in the Uummannaq region but far from Maarmorilik the same year. It must be expected that this ratio will be the same in bottom and surface water, if the only source to contamination of the surface water is upmixing of the polluted bottom water. The second last column in Table 4.2 shows the result of a statistical test (Students t-test) of the two ratios. The column shows the probability that the observed difference could have appeared by chance even if the to ratios actually were identical. In the cases where the difference is significant at the 0.05 level, we have indicated a possible cause in the last column of the table.

Table 4.2. Zinc/lead relationship in bottom and surface water of Affarlikassaa, relative standard error (r.S.E), probability (p), see text.

Year	Bottom water		Surface water		p	Elevation in surface water
	Zn/Pb	r.S.E.*	Zn/Pb	r.S.E.*		
1975	1.47	1.58	1.16	1.60	0.72	
1976	1.32	1.37	1.55	1.21	0.66	
1977	1.33	1.20	3.16	1.61	0.11	
1978	4.37	1.54	7.19	1.73	0.49	
1979	2.09	1.15	11.10	1.34	0.00006	Zn
1980	2.31	1.36	7.69	2.16	0.16	
1981	0.89	1.23	0.40	1.59	0.12	
1982	1.28	1.13	0.67	1.50	0.15	
1983	2.70	1.32	2.03	1.57	0.60	
1984	2.24	1.09	4.38	1.35	0.04	Zn
1985	1.82	1.11	1.38	1.35	0.40	
1986	2.83	1.14	2.61	1.28	0.77	
1987	1.17	1.24	0.50	1.88	0.21	
1988	0.83	1.08	0.45	3.01	0.59	
1989	0.60	1.06	1.52	1.71	0.10	
1990	2.74	1.10	1.52	1.26	0.03	Pb
1991	30.3	1.08	7.52	1.30	0.00005	Pb
1992	16.8	1.14	9.80	1.24	0.04	Pb
1993	113.2	1.20	25.97	1.51	0.004	Pb
1994	83.4	1.27	15.36	1.25	0.00005	Pb
1995	128.9	1.18	8.74	1.41	0.0000007	Pb
1996	108.7	1.25	1.74	4.22	0.01	Pb
1998	173.8	1.22	12.9	1.40	0.000002	Pb
2000	54.23	1.31	-18.20			
2002	79.77	1.16	22.22	1.49	0.007	
2005	194	1.40	37	1.67	0.06	
2007	374	1.41	365	3.41	0.99	

In the period 1991 to 1998 it is notable that the lead concentration in the surface water could not be explained by mixing of the bottom water. Other sources therefore must have been more important after mine closure. This could be waste rock dumps, runoff to coastal areas of dust or concentrate dispersed during the mine operation. In 2000, 2002 and 2005 lead concentrations in the surface water of Affarlikassaa have decreased further and are close to or not different from concentrations at the reference site.

4.3 Seaweed

At each station two samples of seaweed (*Fucus vesiculosus* or *Fucus distichus*) were collected at several metres distance. Growing tips from seaweed were cut off and analyzed for lead and zinc. Results are shown in Annex 3. For each station the geometric mean concentration was computed and used for further calculations.

4.3.1 Spatial trend

Lead levels found are shown in Figure 4.7 and zinc levels in Figure 4.8. These may be compared with each other and with lead and zinc levels found elsewhere in Greenland. Ideally they should be compared with levels found before mining started, but no reliable data exist. It is likely that lead and zinc levels were elevated locally in the fjords caused by natural release of metals from mineralization. Locally elevated lead and zinc concentrations in seaweed have been found earlier in an area with known lead-zinc mineralizations at Appat (Johansen et al. unpubl.).

Figure 4.7. Lead concentration (µg/g) in seaweed from sampling stations close to Maarmorilik (above) and further away (below).

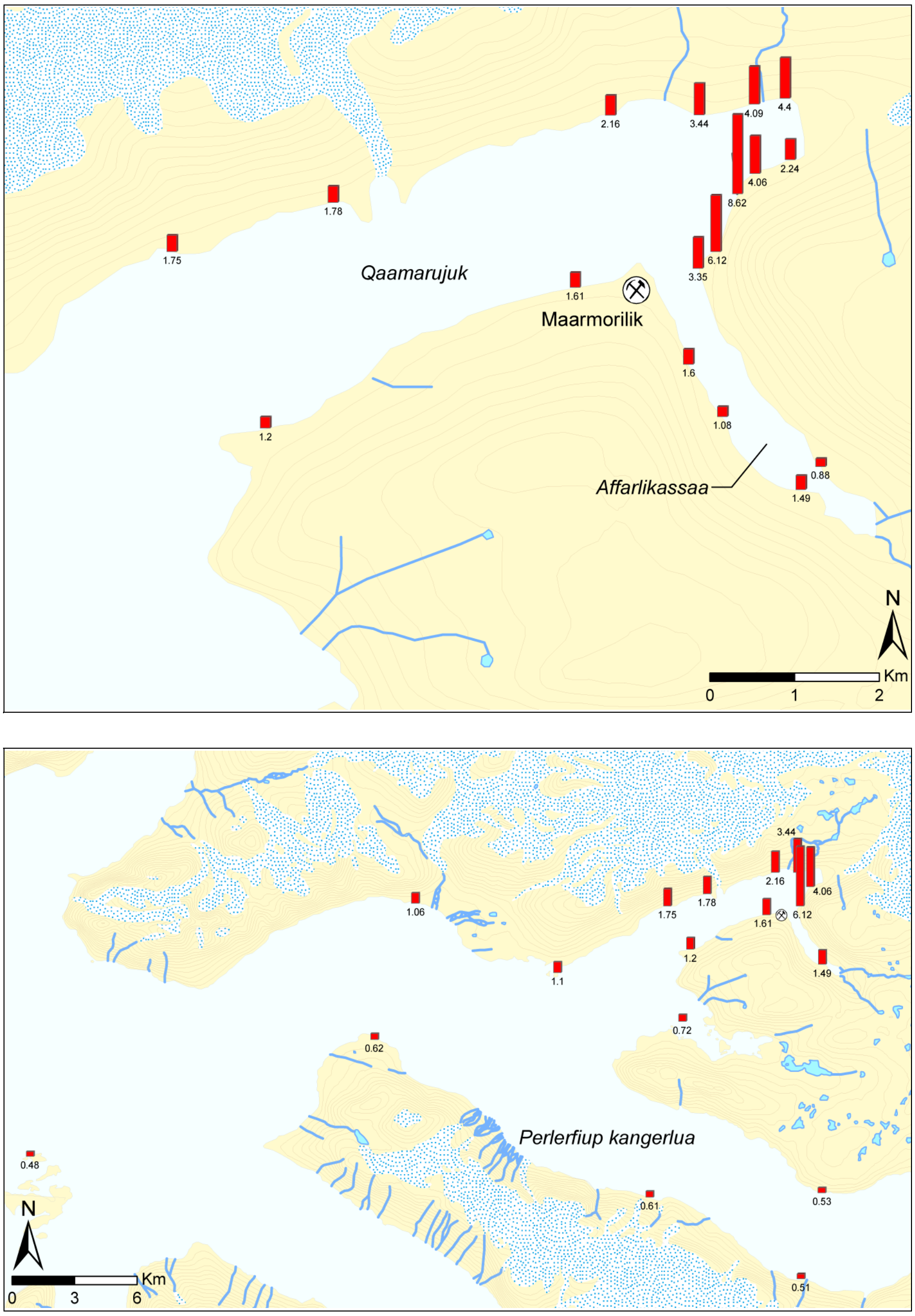
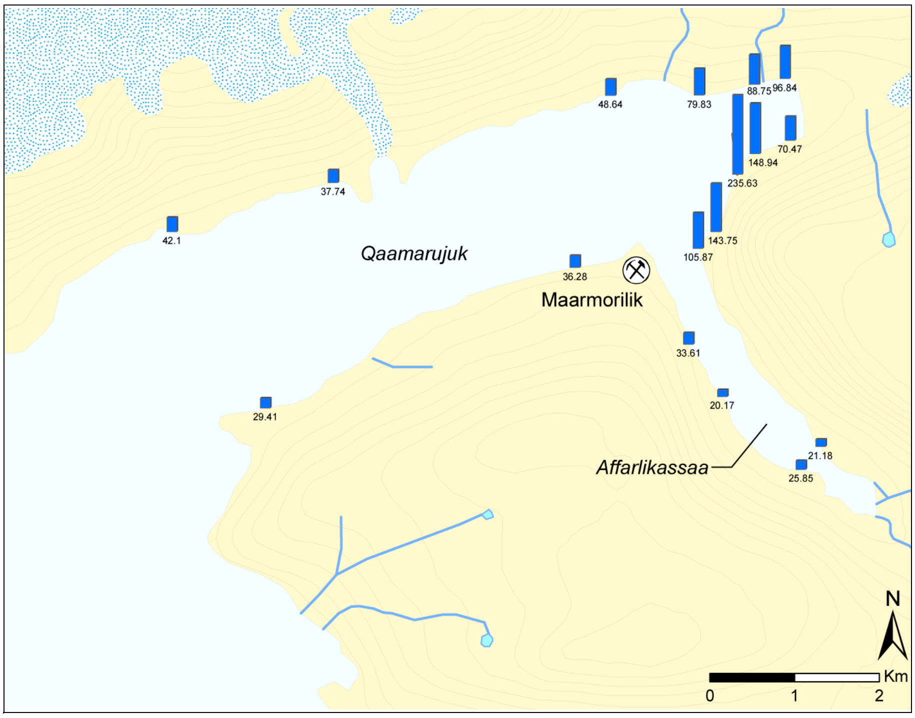
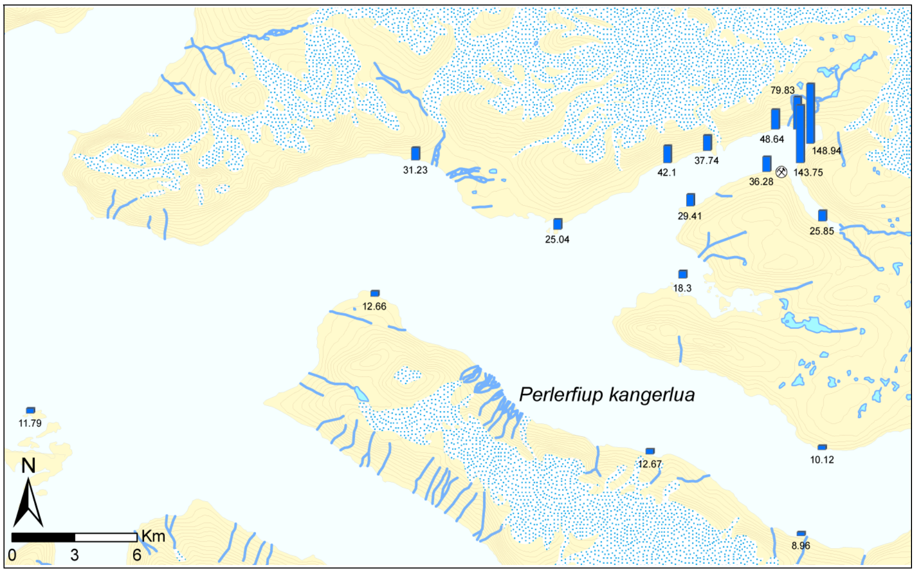


Figure 4.8. Zinc concentration (µg/g) in seaweed from sampling stations close to Maarmorilik (above) and further away (below).





In Greenland areas with no known local sources we have found lead levels in the range 0.2-0.4 µg/g and zinc levels in the range 7-17 µg/g in brown seaweed (Riget et al. 1993, 1995b). Compared to these, lead levels are elevated in most of the study area, viz. in Affarlikassaa, Qaamarujuk and Perlerfiup kangerlua (Figure 4.7). The highest levels are found below the Black Angel Mountain and in inner Qaamarujuk. Here levels are elevated by a factor of about 100, indicating that this area is the main source (probably waste rock dumps and remains of these). In the remaining part of Qaamarujuk and in Affarlikassaa levels are elevated by a factor of about 5. Decreasing concentrations are seen towards west, but the trend is only week and there are higher concentrations in the western part of the study area than could be expected, if the area at Maarmorilik was the only source. Other sources could be dust dispersed to land and coastal areas while mining took place.

The pattern for zinc levels in seaweed is similar to that of lead, except that zinc levels are only elevated by a factor of about 10-20 in inner Qaamarujuk and the area affected is smaller and does not include inner Perlerfiup kangerlua and the southern coast of this fjord (Figure 4.8).

4.3.2 Time trend

The pollution with lead and zinc in seaweed in the fjords at Maarmorilik has been monitored systematically since 1982. In the temporal trend analyses of lead and zinc in seaweed it has been assumed that no systematic difference exists between the two Fucus species analyzed (*Fucus vesiculosus* and *distichus*), which was the case in a comprehensive study carried out in Godthåbs Fjord (Riget et al. 1997a). Geometric mean values were calculated for samples at same station in the same year.

The statistical temporal trend analyses followed the ICES (International Council for the Exploitation of the Sea) temporal trend assessment procedure (Nicholson et al. 1998). The log-mean lead concentration is used as the annual index value. The total variation over time is partitioned into a linear and non-linear component. Linear regression analysis is applied to describe the linear component, and a LOESS smoother (locally weighted quadratic least-squares regression smoothing) with a window width of 7 years is applied to describe the non-linear component. The linear and non-linear components are tested by means of an analysis of variance. The theory behind the use of smoothers in temporal trend analyses is described in detail by Fryer and Nicholson (1999). A significance level of 5% was applied.

The results of the temporal trend analysis can be interpreted as follows:

- Both log-linear and non-linear trend not significant – no temporal trend.
- Log-linear trend significant, non-linear trend not significant – log-linear trend (exponential trend)
- Both log-linear trend and non-linear trend significant – non-linear trend
- Log-linear trend not significant, non-linear trend significant – non-linear trend

The temporal trend analysis also gives the overall annual change estimated from the log-linear regression.

The results of the temporal trend analysis in seaweed are shown in Table 4.3-4.4 and Figure 4.9-4.10. The analysis has been conducted for the whole monitoring period and for the period after mine closure (1990).

In 1990 the concentration of lead and zinc in seaweed increased significantly in all areas monitored. The reason may be the pollution created by digging up waste rock and dumping it into Affarlikassaa and a higher concentration of dissolvable lead in the ore processed in the last months of the mining. The digging up and dumping of waste rock caused a release of heavy metals with a lead-zinc ratio significantly higher than 1 (about 10), and the last ore processed released zinc and lead with a ratio significantly below 1. Primarily the lead concentration in seaweed increased in 1990. Therefore it appears likely that the main explanation of this increase was the last ore processed. In the statistical analyses the 1990 data were not included, since these data probably were caused by an event that is not typical for the metal release during mining.

Table 4.3. Results of the temporal trend analyses of the lead concentrations in seaweed. Significance at the 5% level is shown by "sign" and non-significance by "–" for both the log-linear trend and the non-linear trend components. The overall annual change during the total period is given.

Seaweed – Pb	Whole period (without1990)			After 1990		
Station/Year	Log-linear trend	Non-linear trend	Annual change	Log-linear trend	Non-linear trend	Annual change
T1, 1987-2005	sign	-	-10.8%	sign	sign	-10.7%
T2, 1985-2007	sign	sign	-10.0%	sign	sign	-8.9%
T3, 1984-2007	sign	-	-11.2%	sign	-	-9.4%
T5, 1982-2007	sign	-	-9.5%	sign	sign	-9.4%
T6, 1988-2007	sign	-	-11.0%	sign	-	-9.8%
T7, 1988-2005	sign	-	-10.5%	sign	-	-8.2%
T10, 1981-2007	sign	-	-11.3%	sign	sign	-9.0%
T12Ø, 1983-2007	sign	sign	-11.1%	sign	sign	-5.1%
T12SW, 1988-2007	sign	-	-8.3%	sign	-	-8.0%
T15, 1986-2007	sign	-	-6.4%	-	-	-6.1%
T15A, 1986-2007	sign	-	-6.3%	-	-	-5.8%
T17, 1981-2007	sign	-	-7.8%	-	-	-4.2%
T17A, 1986-2007	sign	-	-7.6%	sign	-	-5.5%
T17B, 1986-2007	sign	-	-4.6%	-	-	-3.96%
T17C, 1986-2007	-	-	-3.6%	-	-	-3.2%
T22, 1986-2007	sign	sign	-10.2%	sign	-	-6.2%
T25, 1982-2007	sign	-	-9.2%	sign	-	-5.2%
T29, 1981-2007	sign	sign	-9.0%	sign	-	-4.3%
T30, 1981-2007	sign	-	-9.2%	sign	-	-4.8%
T36, 1982-2007	sign	sign	-6.6%	-	-	-0.4%
T37, 1982-2007	sign	-	-8.2%	-	-	-1.2%
T38, 1982-2007	sign	-	-6.7%	-	-	+0.9%
St. F, 1988-2007	-	-	-2.0%	-	-	+1.1%
St. G, 1988-2007	-	-	-1.6%	-	-	+1.7%
St. V, 1988-2007	-		-2.0%	-	-	-1.1%
St. L, 1982-2007	sign	sign	-6.4%	-	-	+2.9%

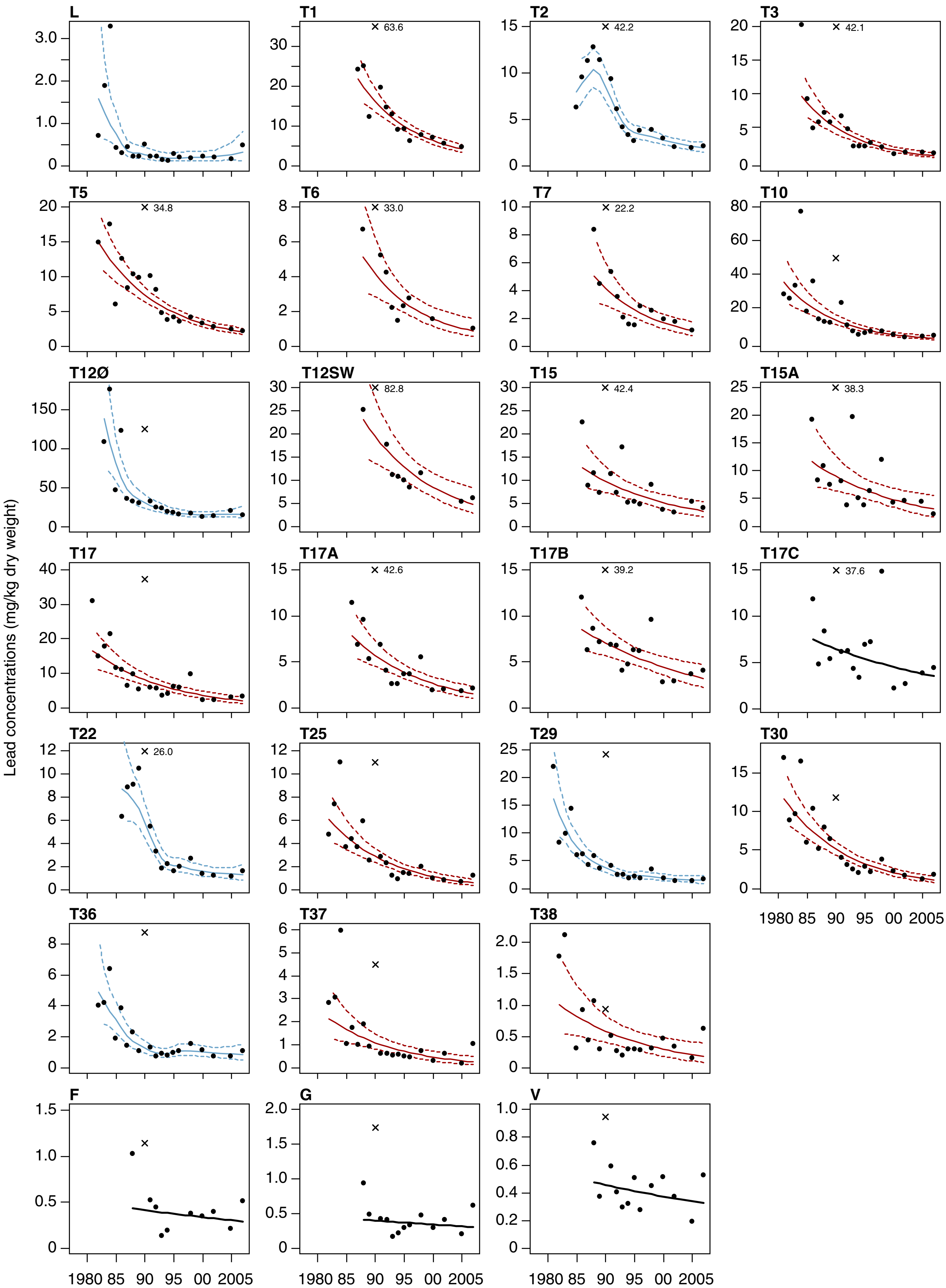


Figure 4.9. Temporal trend of the lead concentrations (mg/kg dry weight) in seaweed. Points denotes annual geometric mean concentration, solid line together with 95% confidence broken lines are given when significant trend was found in the temporal trend analysis. Solid line alone is given when no significant trend was found. Red line indicates a log-linear trend and blue line a non-linear trend.

Over the entire monitoring period lead concentrations in seaweed have decreased at all stations. This decrease, ranging from 1.6 to 11.3% per year, is significant at the 0.05 level for nearly all stations. Also at most stations the decrease may be described as a log-linear trend, meaning an exponential decrease. After mine closure in 1990 lead concentrations have also decreased, but this decrease is significant at fewer stations and the annual change is smaller than for the whole monitoring period. At the stations farthest from Maarmorilik the lead concentration has not changed after 1990. This is to be expected since concentrations here are similar to the levels found at reference sites unaffected by known local sources.

Table 4.4. Results of the temporal trend analyses of the zinc concentrations in seaweed. Significance at the 5% level is shown by "sign" and non-significance by "–" for both the log-linear trend and the non-linear trend components. The overall annual change during the total period is given.

Seaweed – Zn	Whole period (without1990)			After 1990		
Station/Year	Log-linear trend	Non-linear trend	Annual change	Log-linear trend	Non-linear trend	Annual change
St. L, 1982-2007	-	-	0%	-	-	+1.2%
T1, 1987-2005	sign	-	-3.4%	sign	-	-3.3%
T2, 1985-2007	sign	sign	-5.4%	sign	-	-4.6%
T3, 1984-2007	sign	-	-5.1%	sign	-	-6.4%
T5, 1982-2007	sign	-	-5.1%	sign	-	-4.1%
T6, 1988-2007	sign	-	-8.0%	sign	-	-7.7%
T7, 1988-2005	sign	-	-5.7%	sign	-	-5.7%
T10, 1981-2007	sign	-	-3.9%	sign	-	-2.9%
T12Ø, 1983-2007	sign	-	-3.3%	-	-	-0.9%
T12SW, 1988-2007	-	-	-3.1%	-	-	-2.4%
T15, 1986-2007	sign	-	-3.1%	-	-	-2.4%
T15A, 1986-2007	sign	-	-4.2%	sign	sign	-4.4%
T17, 1981-2007	sign	-	-2.9%	sign	-	-4.1%
T17A, 1986-2007	sign	sign	-4.6%	sign	sign	-5.2%
T17B, 1986-2007	sign	-	-2.3%	sign	-	-3.2%
T17C, 1986-2007	sign	-	-2.4%	-	-	-2.1%
T22, 1986-2007	sign	-	-5.3%	sign	-	-5.2%
T25, 1982-2007	sign	-	-4.7%	sign	-	-5.1%
T29, 1981-2007	sign	-	-4.2%	sign	sign	-4.2%
T30, 1981-2007	sign	-	-4.4%	sign	sign	-4.5%
T36, 1982-2007	sign	-	-3.1%	sign	sign	-2.7%
T37, 1982-2007	sign	-	-2.5%	-	-	-0.2%
T38, 1982-2007	-	-	-1.2%	-	-	-0.8%
St. F, 1988-2007	-	-	-2.9%	-	-	-2.4%
St. G, 1988-2007	-	-	-2.3%	-	-	-1.8%
St. V, 1988-2007	sign	-	-3.2%	-	-	-3.3%

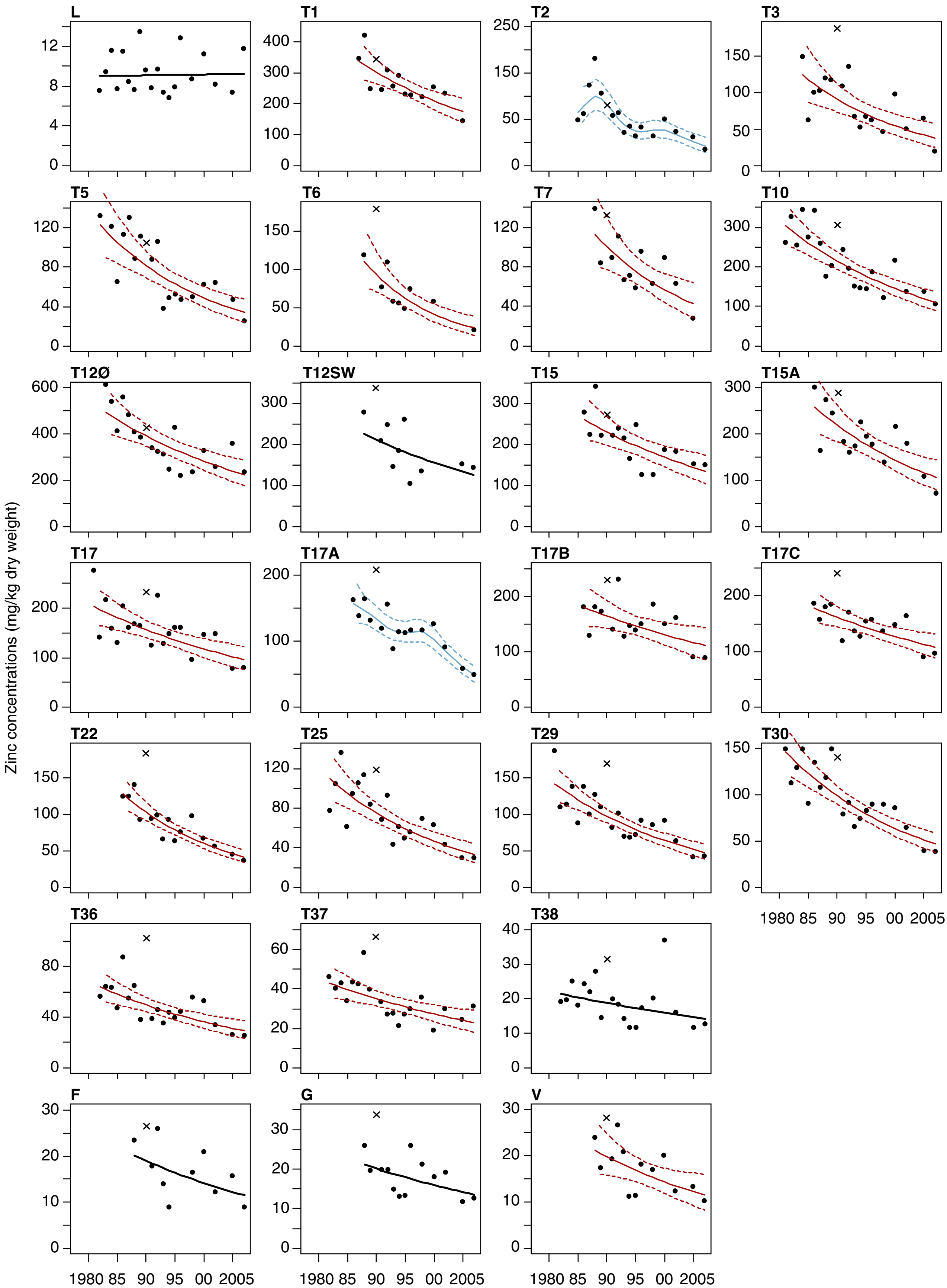


Figure 4.10. Temporal trend of the zinc concentrations in seaweed. Points denotes annual geometric mean concentration, solid line together with 95% confidence broken lines are given when significant trend was found in the temporal trend analysis. Solid line alone is given when no significant trend was found. Red line indicates a log-linear trend and blue line a non-linear trend.

Over the entire monitoring period zinc concentrations in seaweed have decreased at all stations, except station L (farthest off Maarmorilik). This decrease, ranging from 1.2 to 8.0% per year, is significant at the 0.05 level for nearly all stations. Also at most stations the decrease may be described as a log-linear trend, meaning an exponential decrease. After mine closure in 1990 zinc concentrations have also decreased at most stations, but this decrease is significant at fewer stations and the annual change is smaller than for the whole monitoring period. At the stations farthest off Maarmorilik zinc concentrations have not changed after 1990. This is to be expected since concentrations here are similar to the levels found at reference sites unaffected by known local sources.

In order to illustrate an overall, simplified time trend of lead and zinc concentrations in seaweed, selected stations sampled have been divided into four sub areas according to concentrations levels (and distance to the source). Mean concentrations from sub areas have been computed and are presented in Figures 4.11 and 4.12. The sub areas (as shown in the legends of the figures) include these sampling stations:

At the mine: station 10
3-5 km from the mine: stations T29 and T30
12-19 km from the mine: stations T36 and T37
35 km from the mine: station L.

For each sub area the mean concentration was computed.

Figure 4.11. Lead concentration (µg/g) in seaweed in areas at different distances from the mine.

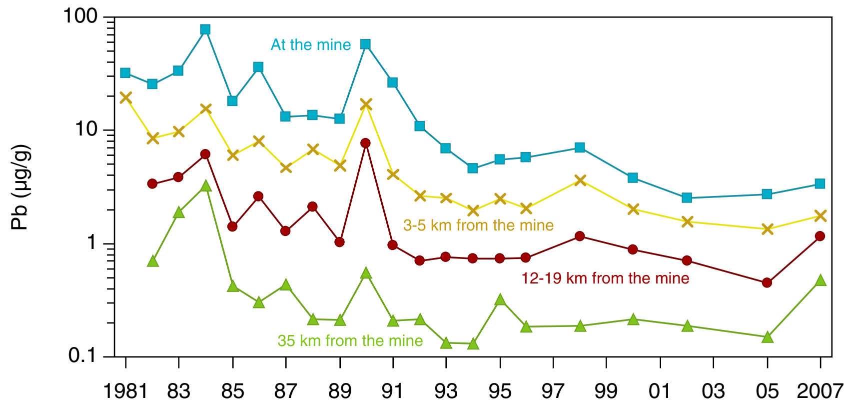
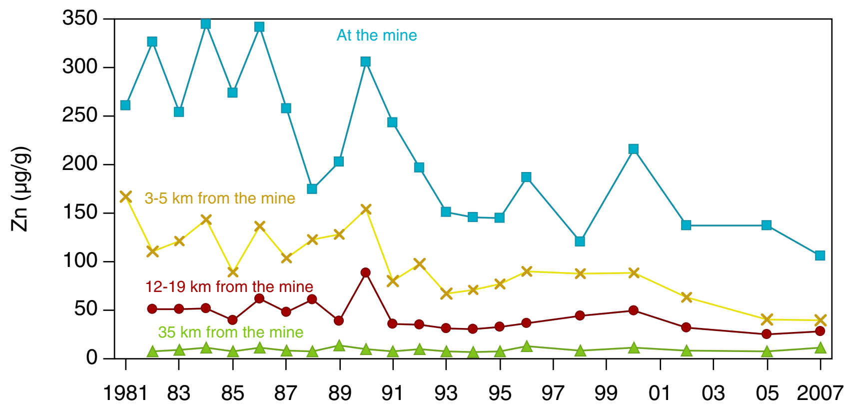


Figure 4.12. Zinc concentration (µg/g) in seaweed in areas at different distances from the mine.



4.3.3 Seaweed – overall evaluation

The lead and zinc concentration in seaweed has been decreasing over the entire monitoring period (since 1981). This trend in most cases is exponential. The lead concentration has decreased faster than the zinc concentration. In 2007 lead concentrations were elevated in all of the study area: Affarlikassaa, Qaamarujuk and Perlerfiup kangerlua. Zinc concentrations were elevated in a smaller area: in Affarlikassaa and Qaamarujuk but outside these fjords only on the northern coast of Perlerfiup kangerlua.

4.4 Blue mussel

At most stations two size groups of blue mussel (*Mytilus edulis*) were collected and prepared as described in chapter 2 and analyzed for lead and zinc as described in chapter 3. The results are shown in Annex 4. Earlier we have sampled both resident mussels and mussels which were transplanted from an area unaffected by the mine to areas at the mine and left there for a year in order to study the temporal trend of the lead contamination of the mussels. In 2007, however, only resident mussels were collected. These are primarily collected in order to assess the spatial trend of the lead and zinc contamination.

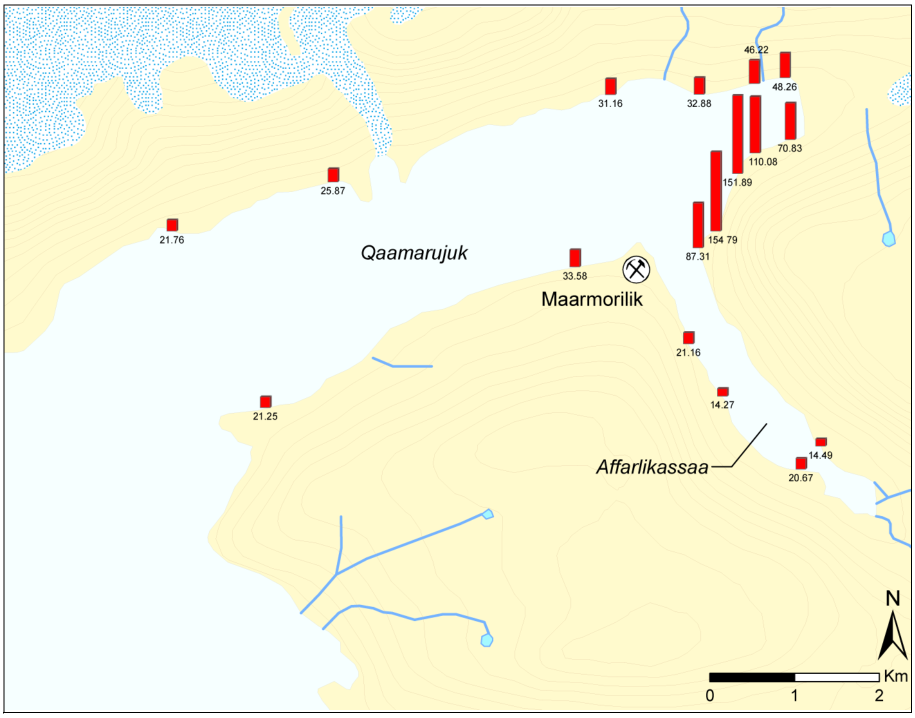
4.4.1 Spatial trend

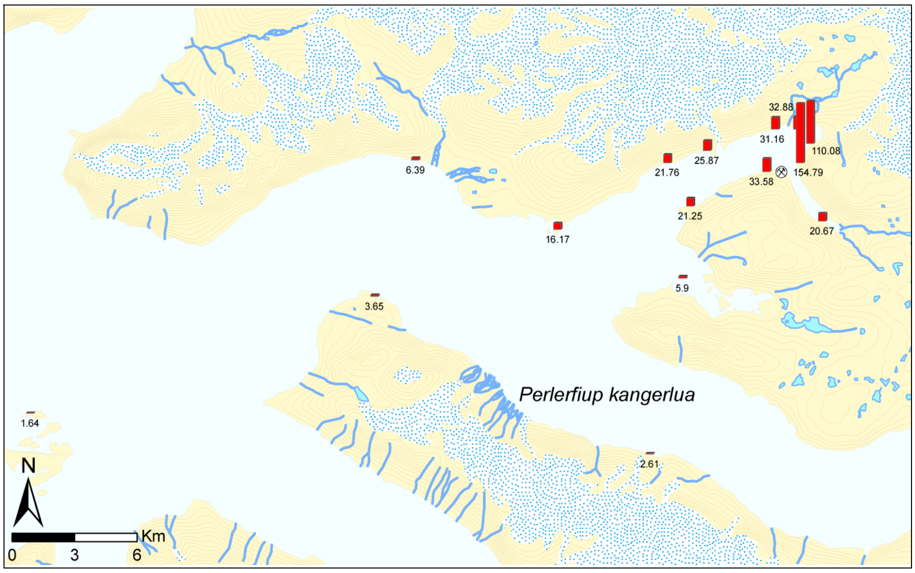
Lead concentrations found in blue mussels are shown in Figure 4.13 and Figure 4.14.

The concentrations found at Maarmorilik may be compared with each other and with lead levels found elsewhere in Greenland. As with seaweed ideally they should be compared with levels found before mining started, but no reliable data exist. It is likely that lead levels were elevated locally in the fjords caused by natural release of metals from mineralizations. In blue mussels from the Uummannaq region with no known local sources we have found lead and zinc concentration (µg/g dry weight) as shown below:

Lead: 0.87-1.09 (mean 0.98), zinc: 92-183 (mean 120), 5 samples.

Figure 4.13. Lead concentration (µg/g) in small blue mussels (5-6 cm shell length) from sampling stations close to Maarmorilik (above) and further away (below).

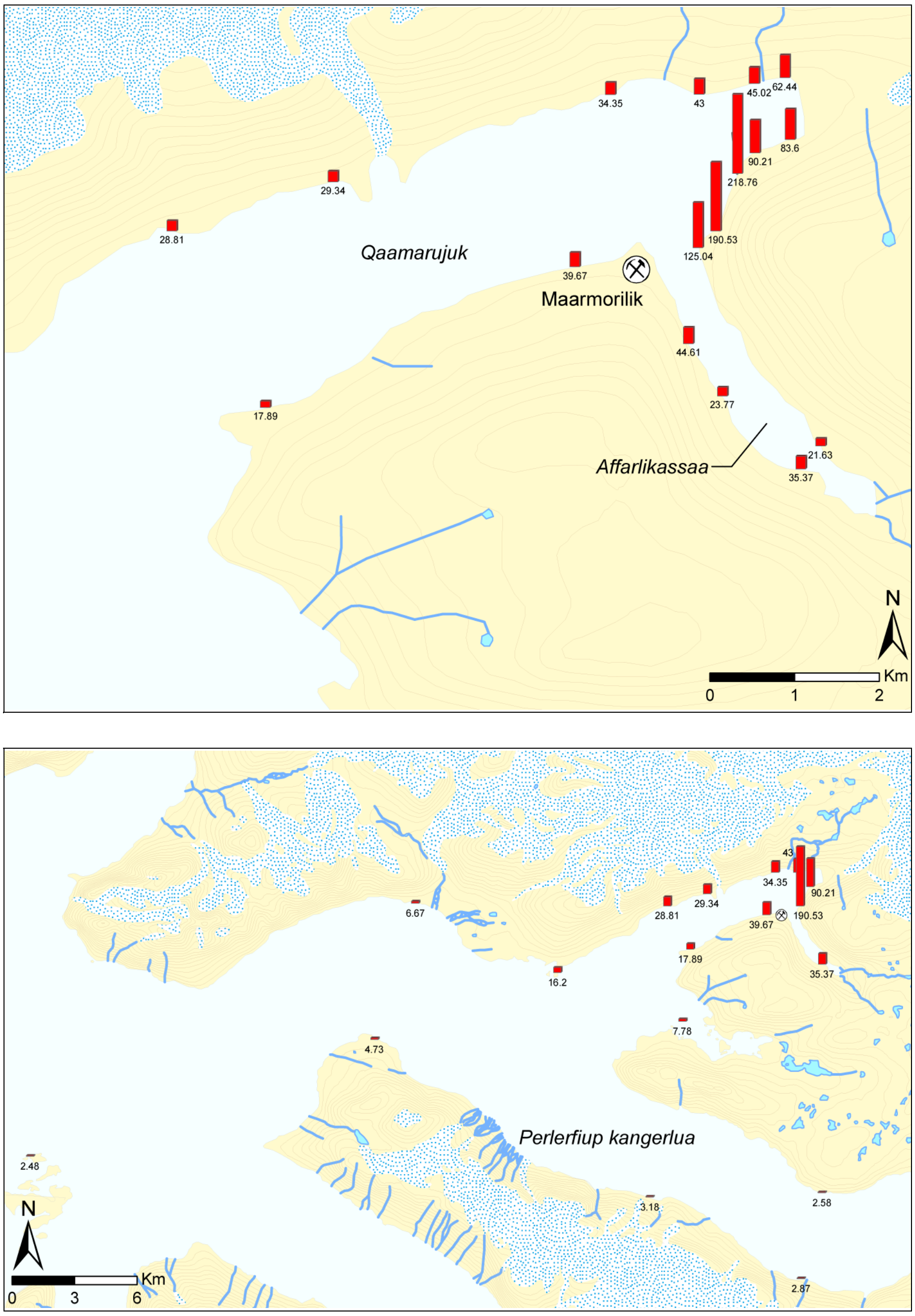




Compared to these levels the lead concentration in blue mussels is elevated in all of the study area (Figure 4.13 and 4.14), whereas the zinc concentration is only elevated in a small area close to Maarmorilik (Annex 4). In the most affected area below the Black Angel Mountain, lead concentrations are elevated by a factor of 100-200, in Affarlikassaa and most of Qaamarujuk by a factor of 20-40 and outside this fjord in Perlerfiup kangerlua and at Qeqertat by a factor of 2-10.

The lead concentration is higher in large than in small mussels, because large mussels have been exposed to lead for more years than small, and because lead is only released at a very small rate from the mussels, if the exposure ceases (Riget et al. 1997b).

Figure 4.14. Lead concentration (µg/g) in large blue mussels (shell length 6-7 cm) from sampling stations close to Maarmorilik (above) and further away (below).



4.4.2 Time trend

A time trend analysis for the lead and zinc concentration in blue mussel was conducted using the same method as described in the section dealing with seaweed (section 4.3.2). The result of this analysis is shown in Table 4.5 and 4.6.

Table 4.5. Results of the temporal trend analyses of lead concentrations in blue mussels of different size groups. Significance at the 5% level is shown by "sign" and non-significance by "–" for both the log-linear trend and the non-linear trend components. The overall annual change during the period is given.

Blue mussels Pb	**Whole period (≤ 7 years of data)**			**After 1990 (≥ 6 years of data)**		
Station/Year	**Log-linear trend**	**Non-linear trend**	**Annual change**	**Log-linear trend**	**Non-linear trend**	**Annual change**
St. L, <1g, 1982-2007	sign	-	-5.8%	sign	-	-6.6%
St. L, 1-2g, 1982-2007	sign	sign	-9.2%	sign	sign	-6.5%
St. L, >2g, 1982-2004	sign	-	-6.3%	sign	-	-11.1%
T5, 1-2g, 1982-2007	sign	sign	-14.7%	sign	-	-23.7%
T10, 1-2g, 1977-2005	sign	-	-9.0%			
T12Ø, 1-2g, 1983-2007	sign	-	-10.3%			
T12Ø, >2g, 1987-1995	-	-	-7.7%			
T12SW, 1-2g, 1988-2007	sign	-	-11.6%	sign	-	-12.0%
T15, <1g, 1986-2007	sign	-	-16.0%	sign	-	-13.7%
T15, 1-2g, 1986-1998	sign	-	-4.5%	-	-	-5.1%
T15A, 1-2g, 1986-2005	sign	sign	-11.7%			
T15A, >2g, 1986-1993	-	-	+0.3%			
T17, <1g, 1977-2007	sign	sign	-9.7%			
T17, 1-2g, 1982-2007	sign	sign	-9.2%			
T17, >2g, 1983-1993	-	-	-1.0%			
T17A, <1g, 1976-2007	sign	sign	-8.4%	sign		-18.0%
T17A, 1-2g, 1978-1996	sign	-	-6.0%			
T17B, <1g, 1986-2007	sign	sign	-14.5%			
T17B, 1-2g, 1986-2007	sign	sign	-12.3%	sign	-	-16.4%
T17C, 1-2g, 1986-2005	sign	sign	-12.3%			
T22, 1-2g, 1986-2005	sign	sign	-16.1%	sign	-	-23.3%
T25, <1g, 1982-2007	sign	-	-13.7%			
T25, 1-2g, 1982-2002	sign	sign	-8.5%	sign	sign	-22.5%
T29, <1g, 1977-2007	sign	sign	-9.6%	sign	-	-18.0%
T29, 1-2g, 1976-2002	sign	-	-1.5%	sign	sign	-22.5%
T30, <1g, 1976-2007	sign	sign	-10.1%			
T30, 1-2g, 1976-2002	sign	sign	-4.4%	sign	-	-12.6%
T36, <1g, 1978-2007	sign	sign	-10.5%	sign	-	-4.8%
T36, 1-2g, 1978-2002	sign	sign	-6.7%	sign	-	-20.6%
T36, >2g, 1978-2002	sign	-	-5.3%			
T37, <1g, 1981-2007	sign	-	-14.5%			
T37, 1-2g, 1982-2000	sign	-	-6.7%	-	-	-2.8%
T37, >2g, 1982-1995	sign	sign	-10.9%			
T38, 1-2g, 1981-2005	sign	sign	-16.3%	sign	-	-14.5%
T38, >2g, 1981-1998	sign	-	-5.8%			
St. G, 1-2g, 1982-2007	sign	-	-14.2%	sign	sign	-6.5%
St. G, >2g, 1982-2005	sign	sign	-18.2%			

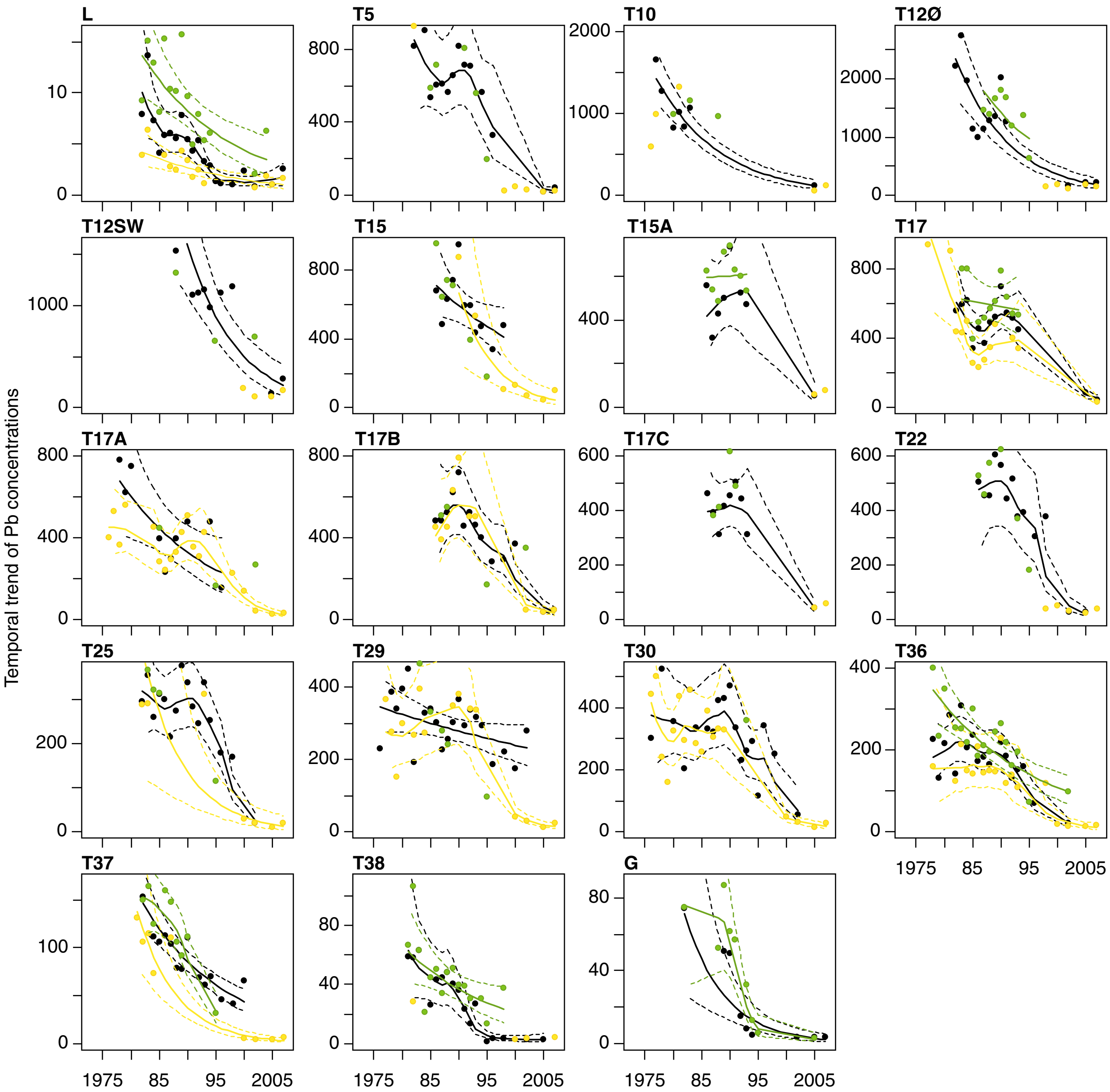


Figure 4.15. Temporal trend of Pb concentrations in blue mussels. Yellow colours denote results of size group < 1g, black colours denote results of size group 1-2 g and green colour denotes results of size group > 2g. Points and solid trend line together with 95% confidence broken lines are given when significant trend was found in the temporal trend analysis. Points and solid line are given when no significant trend was found.

Table 4.6. Results of the temporal trend analyses of zinc concentrations in blue mussels. Significance at the 5% level is shown by "sign" and non-significance by "–" for both the log-linear trend and the non-linear trend components. The overall annual change during the period is given.

Blue mussels Zn	Whole period (>=7 years of data)			After 1990 (>= 6 years of data)		
Station/Year	Log-linear trend	Non-linear trend	Annual change	Log-linear trend	Non-linear trend	Annual change
St. L, 1982-2007	sign	-	-1.2%	-	-	-1.2%
T5, 1982-2007	sign	-	-7.1%	sign	-	-9.2%
T10, 1976-2007	sign	-	-3.3%			
T12Ø, 1982-2007	sign	-	-3.5%	-	-	-0.2%
T12SW, 1988-2007	-	-	-2.5%	-	-	-1.2%
T15, 1986-2007	sign	-	-4.6%	-	-	-3.5%
T15A, 1986-2007	sign	-	-3.7%			
T17, 1977-2007	sign	sign	-3.2%			
T17A, 1976-2007	sign	sign	-3.2%	sign	-	-6.9%
T17B, 1986-2007	sign	-	-5.0%			
T17C, 1986-2005	sign	sign	-2.5%			
T22, 1986-2005	sign	-	-6.8%	sign	-	-7.2%
T25, 1982-2007	sign	sign	-3.8%	sign	-	-6.4%
T29, 1977-2007	sign	sign	-2.7%	sign	-	-5.9%
T30, 1976-2007	sign	sign	-2.5%	sign	-	-5.6%
T36, 1978-2007	sign	-	-3.4%	sign	-	-5.0%
T37, 1981-2007	sign	-	-3.5%	sign	-	-4.8%
T38, 1981-2005	sign	-	-2.7%	-	-	-1.3%
St.G, 1982-2007	sign	sign	-3.9%	-	-	-1.0%

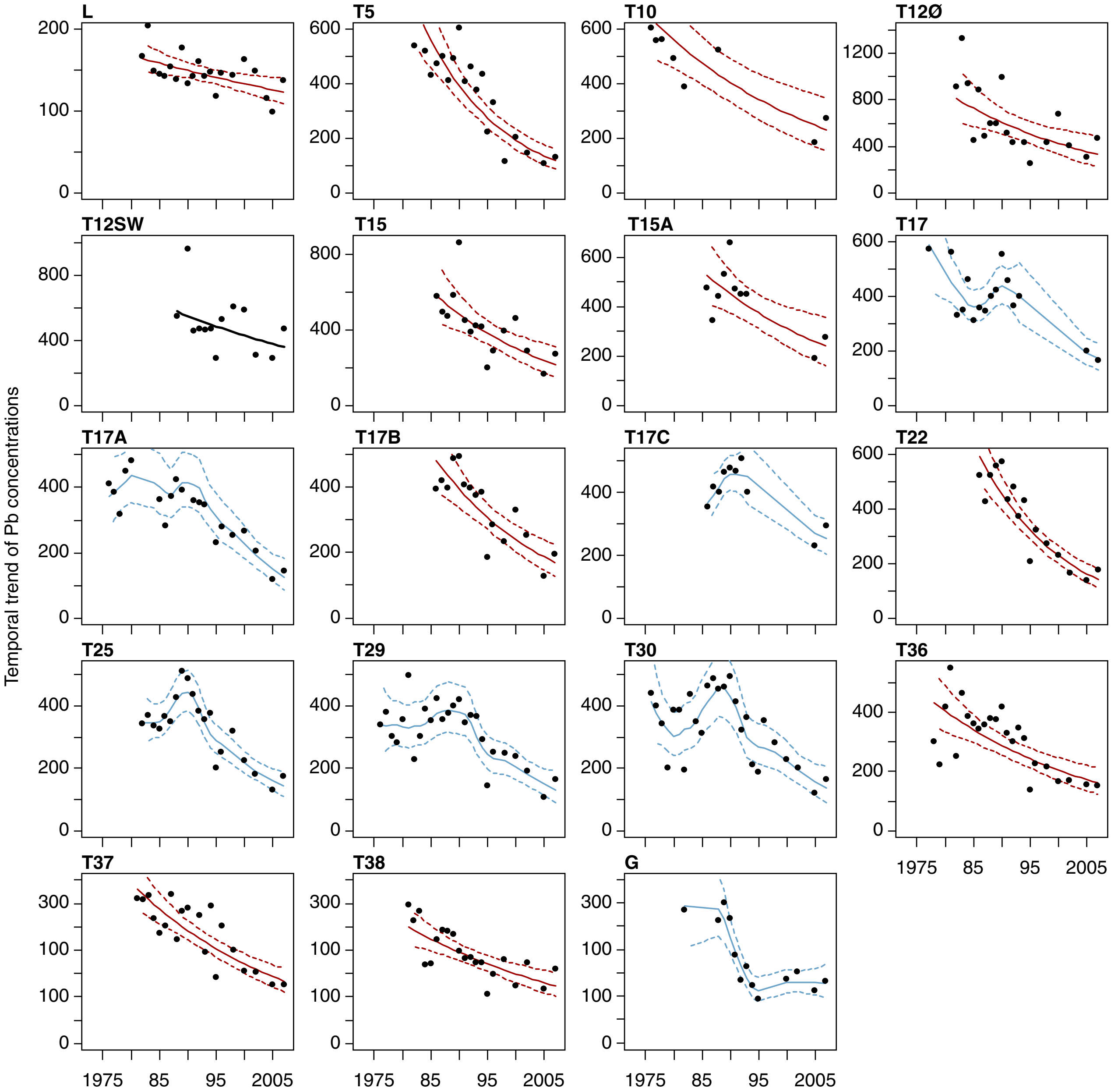


Figure 4.16. Temporal trend of zinc concentrations in blue mussels. Red colours denote results of size group < 1g, black colours denote results of size group 1-2 g and green colour denotes results of size group > 2g. Points and solid trend line together with 95% confidence broken lines are given when significant trend was found in the temporal trend analysis. Red colours indicate a log-linear trend and blue colours a non-linear trend. Points and solid line are given when no significant trend was found.

Lead concentrations in blue mussels have decreased in the whole monitoring period at all stations, except for large mussels at station T15A. However, at this station there are no data for large mussels after 1993, and in small mussels there is a significant decrease of lead concentrations. The annual rate of decrease during the whole period ranges from 5.8 to 16.0% in small mussels (<1 g) in the whole study area and follows a significant log-linear trend. In medium sized mussels (1-2 g) the lead concentration also decreases and may be described as a significant log-linear trend with an annual rate of decrease from 1.5 to 16.3%. In large mussels (>2 g) the general trend is also a decline of lead concentrations, but data are fewer and in many cases cover a shorter period and with no data from recent years.

After mine closure in 1990 the lead concentration in blue mussels has decreased at a faster rate than over the whole monitoring period (Figure 4.15). At most stations this decrease may be described as a significant log-linear trend and the annual rate of decrease is between 2.8 and 22.5% and in most cases between 10 and 20%.

Zinc concentrations in blue mussels have also decreased but the rate is lower than for lead, ranging from 1.2 to 7.1% per year in the whole monitoring period and from 0.2 to 7.2% after mine closure (Figure 4.16). At all stations with significant temporal trends, this followed an exponential decrease.

There are two main explanations for this decrease. The first one is the decrease in water concentrations of lead and zinc, in particular after mine closure. Transplantation experiments with blue mussels indicate that the lead exposure decreased with about 80% after mine closure (Riget et al. 1997). The second explanation is that gradually the blue mussels that were polluted during the period of mining will disappear (being eaten or die of natural causes), new generations will emerge and these will be exposed to lower concentrations. Today, 17 years after mine closure it will be difficult to find blue mussels which have been alive while the mine was operating. Blue mussels aged 15 years or more were rarely found in a study of growth in Disko Bay (Theisen 1973).

4.4.3 Restrictions for eating blue mussels

Blue mussels may be collected locally and eaten in Greenland. The elevated lead levels found in the fjords at Maarmorilik implies a risk to human health. This risk has been evaluated by comparing the levels found in the fjord to the “maximum allowed level” for lead in Greenlandic diet items. This level is 1.5 µg/g (wet weight) for mussels (Anon. 2005). As the mean dry weight percentage in the mussels is 15.4, the “maximum allowed level” equals 9.7 µg/g on a dry weight basis.

This level is exceeded on all stations in Affarlikassaa and Qaamarujuk and at Qeqertanguit (station T36) west of Qaamarujuk, but will also be exceeded at some distance outside the area delimited by this station and station T25 at the mouth of Qaamarujuk on the southern coast. In order to fix the area of the coastline where the “maximum allowed level” is exceeded, we have extrapolated between the values found at station T36 and T37 on the northern and between T25 and T33 on the southern coast of Perlerfiup kangerlua. The result is shown in Figure 4.17, and on the coastline shown it is recommended not to collect and eat blue mussels. This area is similar to that found in 2005 (Johansen et al. 2006) but much smaller than before that. Until 2005 it also included all of Perlerfiup kangerlua (Johansen et al. 2003).

It was tested if the lead concentrations found in 2007 were below 10 mg/kg dw (maximum allowed level for lead in mussels) or even below 2 mg/kg dw (approximately 2 times background level). For stations and size groups where a temporal trend analyses (see later) was applied, the fitted value together with the standard error in 2007 was used in the test. In cases where no temporal trend analyses was conducted, the lead concentrations multiplied with 2 times a standard error of 0.28 (on log-scale) which correspond to a relative standard deviation of 1.71, was applied to test whether the concentration was below the described limits. The standard error chosen derived from Station L and was considered as reasonable.

The results in 2007 were that at no stations the lead concentration could be considered below 2 mg/kg dw and only at stations L, F, G, V and T38 the lead concentrations could be considered below 10 mg/kg dw. These results are rather similar to the results in 2005.

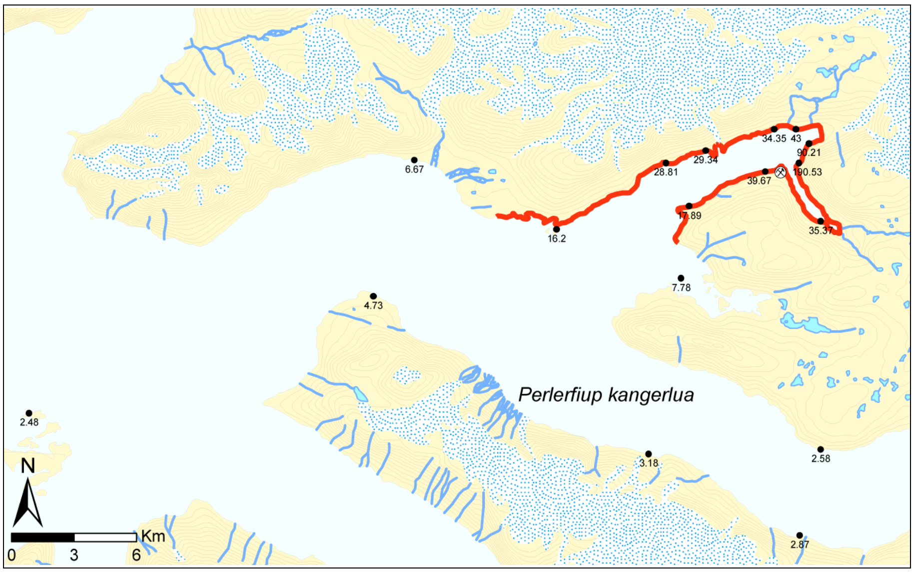


Figure 4.17. Area where it is recommended not to collect and eat blue mussels. Figures show lead concentrations (µg/g on a dry weight basis) in large blue mussels.

4.5 Shorthorn sculpin

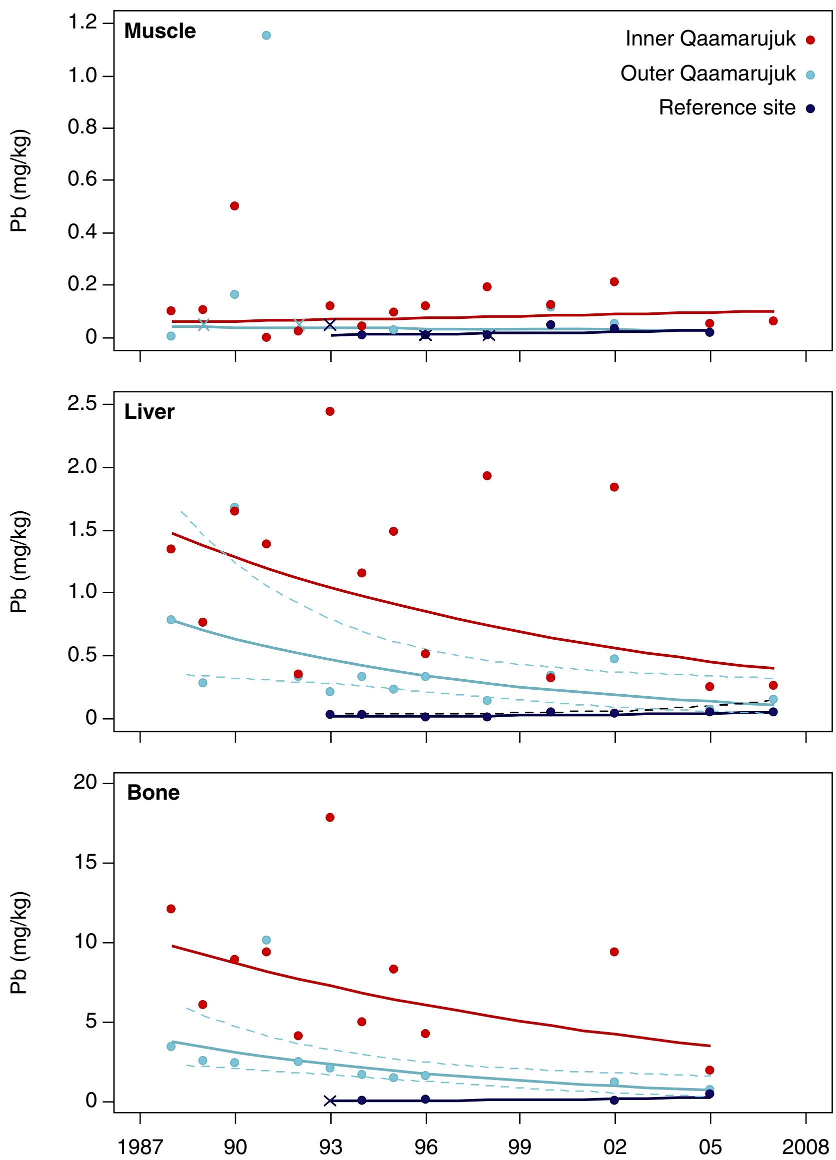
Shorthorn sculpin (*Myoxocephalus scorpius*) is studied in order to assess spatial and time trends of the contamination from the mine. Sculpin is a rather stationary fish species, and therefore a suited indicator of pollution. Only lead is analyzed, since this is the only metal which has been elevated in fish.

A time trend analysis for the lead concentration in sculpin was conducted using the same method as described in the section dealing with seaweed (section 4.3.2). The log-mean lead concentration is used as the annual index value. The result of this analysis is shown in Table 4.7 and Figure 4.18.

Table 4.7. Results of the temporal trend analyses of lead concentrations in shorthorn sculpin. Significance at the 5% level is shown by "sign" and non-significance by "–" for both the log-linear trend and the non-linear trend components. The overall annual change during the period is given. Time period for lead concentrations in sculpin from the reference area is shorter than for inner and outer Qaamarujuk

Shorthorn sculpin Pb	Inner Qaamarujuk			Outer Qaamarujuk			Reference area		
	Log-linear trend	Non-linear trend	Annual change	Log-linear trend	Non-linear trend	Annual change	Log-linear trend	Non-linear trend	Annual change
Liver, 1988-2007[1]	-	-	-6.9%	sign	-	-10.2%	-	-	8.1%
Muscle, 1988-2007[1]	-	-	+2.7%	-	-	-1.5%	-	-	7.8%
Bone, 1988-2007[1]	-	-	-6.0%	sign	-	-9.6%	-	-	15.0%

Figure 4.18. Temporal trend of lead concentrations in shorthorn sculpin. Red colour denotes Inner Qaamarujuk, blue colour Outer Qaamarujuk and black colour reference site. Points and solid trend line together with 95% confidence broken lines are given when significant trend was found in the temporal trend analysis. Points and solid line are given when no significant trend was found.



In muscle tissue there is no trend over time of lead concentrations and these are not elevated compared to the reference site. In both liver and bone tissue the lead concentration has decreased over the monitoring period. However this trend is only significant in Outer Qaamarujuk. Here the annual rate of decrease is about 10%. Concentrations are decreasing towards levels close to those found at the reference station, but are still elevated (approximately a factor 2) and significantly higher both for liver ($p=0.016$) and bone (compared to 2005, $p=0.017$). The test were performed in similar way as described for the blue mussels using the fitted values derived from the temporal trend analyses and testing whether the concentrations at the reference site is significantly lower than in Inner and Outer Qaamarujuk.

The "maximum allowed level" for lead in Greenlandic diet items is 0.2 µg/g (wet weight) for fish meat and 0.3 µg/g (wet weight) in fish liver (Anon. 2005). This value is equal to about 1 µg/g (dry weight). Compared to the "maximum allowed level", the levels found in sculpin is well below in the most recent study periods (Figure 4.18).

4.6 Northern shrimp

Northern shrimp (*Pandalus borealis*) has been studied in order to assess spatial and time trends of the contamination from the mine. Only lead is analyzed, since this is the only metal which has been elevated in the prawns. The prawns were divided into length groups, and of each group the prawns were divided into two samples, one consisting of the meat and the other of the remaining parts (heads and shells).

A time trend analysis for the lead concentration in shrimp was conducted using the same method as described in the section dealing with seaweed (section 4.3.2). The log-mean lead concentration is used as the annual index value. The result of this analysis is shown in Table 4.8 and Figure 4.19.

Table 4.8. Results of the temporal trend analyses of lead concentrations in northern shrimp. Significance at the 5% level is shown by "sign" and non-significance by "–" for both the log-linear trend and the non-linear trend components. The overall annual change during the period is given.

Shrimp Pb	**Inner Qaamarujuk**			**Outer Qaamarujuk**			**Reference area**		
	Log-linear trend	**Non-linear trend**	**Annual change**	**Log-linear trend**	**Non-linear trend**	**Annual change**	**Log-linear trend**	**Non-linear trend**	**Annual change**
Heads and shells, 1988-2007	Sign	sign	-6.9%	sign	sign	-6.6%	-	sign	4.0%
Meat, 1988-2007	-	-	-3.7%	sign	sign	-6.0%	-	-	7.9%

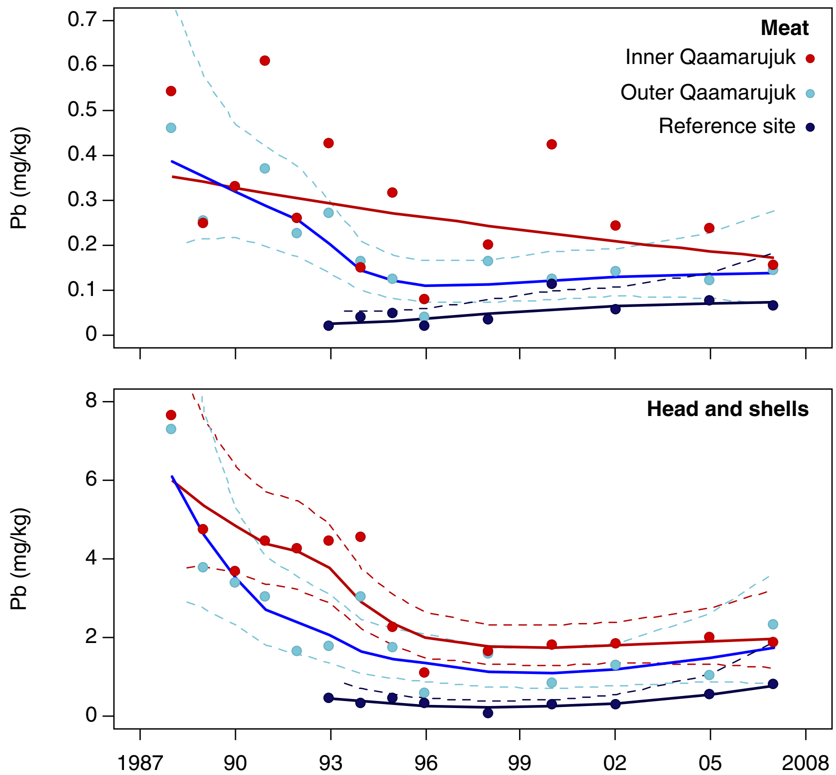


Figure 4.19. Temporal trend of lead concentrations in northern shrimp. Red colour denotes Inner Qaamarujuk, blue colour Outer Qaamarujuk and black colour reference site. Points and solid trend line together with 95% confidence broken lines are given when significant trend was found in the temporal trend analysis. Points and solid line are given when no significant trend was found.

There is a significant decrease of lead concentrations in heads and shells. This is also the case for shrimp meat in Outer Qaamarujuk, but not for the inner fjord. Decreases are between 6 and 6.9% per year since 1988. In heads and shells concentrations are elevated by a factor of about 10 compared to the reference site and differences are in both cases significantly (Inner Qaamarajuk: p=0.02 and Outer Qaamarujuk: p=0.03). Lead concentrations in meat are elevated by a factor of about 2 and this difference is significant in Inner Qaamarujuk (p=0.02) but not in Outer Qaamarujuk (p=0.07). The test were performed in similar way as described for the blue mussels using the fitted values derived from the temporal trend analyses and testing whether the concentrations at the reference site is significantly lower than in Inner and Outer Qaamarujuk.

The "maximum allowed level" for lead in Greenlandic diet items is 0.5 µg/g (wet weight) for shellfish (Anon. 2005). This value is equal to about 2 µg/g (dry weight). Compared to the "maximum allowed level", the levels found in shrimp meat are well below (Figure 4.19).

5 References

Anon. 2005. Bekendtgørelse for Grønland om visse forureninger i fødevarer. Fødevarestyrelsen, bekendtgørelse nr. 891, 22.september 2005.

Asmund, G. 1992. Lead and zinc pollution for marine dumping of waste rock from lead/zinc mining. Pp. 105-112 in: Bandopadhyay & Neilson (eds.) Mining in the Arctic. Balkerma, Rotterdam.

Johansen, P., Riget, F.F., Asmund, G., Josefson, A.B. & Hansen, J.L.S. 2006: Miljøundersøgelser ved Maarmorilik 2005. Danmarks Miljøundersøgelser. - Faglig rapport fra DMU 605: 102 s. (elektronisk).

Møller, J.S. 1984. Hydrodynamics of an Arctic Fjord. Institute of Hydrodynamics and Hydraulic Engineering. Technical University of Denmark. Series Paper 34, 197 pp.

Nicholson, M.D., Fryer, R.J. & Larsen, J.R. 1995. A Robust Method for Analysing Contaminant Trend Monitoring Data. Techniques in Marine Environmental Science. ICES.

Riget, F., Johansen, P. & Asmund, G. 1997a: Baseline Levels and Natural Variability of Elements in Three Seaweed Species from West Greenland. Mar.Poll.Bull. 34(3): 171-176.

Riget, F., Johansen, P. & Asmund, G. 1997b: Uptake and Release of Lead and Zinc by Blue Mussels. Experience from Transplantation Experiments in Greenland. Mar. Poll. Bull. 34(10): 805-815.

Theisen, B. 1973. The growth of Mytilus edulis L. (Bivalvia) from Disko and Thule District, Greenland. Ophelia 12: 59-77.

Annex 1. Metal analyses of lichen

Results are expressed in µg/g dry weight. Species analyzed is *Cetraria nivalis.*

ID #	Station	Pb	Zn
37964	St 2	27.51	28.9
37962	St 3	10.39	20.7
37963	St 5	33.78	44.2
37959	St 6	15.93	30.7
37961	St 10	293.45	106.8
37972	St 12 SW	176.06	114.9
37971	St 12 Ø	56.59	37.9
37973	St 15	33.68	36.6
37974	St 15A	46.55	58.4
37975	St 17	37.27	56.9
37976	St 17A	29.68	46.2
37977	St 17B	106.90	124.0
37978	St 17C	115.10	133.6
37979	St 22	70.69	91.4
37960	St 25	19.26	23.2
37957	St 29	29.45	42.5
37956	St 30	23.62	23.6
37965	St 33	1.02	17.2
37966	St 36	5.58	10.7
37958	St 37	10.72	23.6
37970	St 38	0.79	13.7
37969	V	0.61	8.6
37967	G	0.90	10.5
37968	L	0.57	12.8
37955	Saatut	0.75	15.1

Annex 2. Metal analyses of seawater

Results are in ng/g. Detection limits are shown in the last row. Two samples (0 m at St. 3 on 3 August and 50 m at the reference station) appear to be contaminated with zinc during sampling or analysis.

	Depth, m	Co	Ni	Cu	Zn	Cd	Pb
St. 1	0	0.045	0.685	0.295	5.964	0.037	0.024
25 August	10	0.046	0.729	0.308	8.085	0.034	0.032
	20	0.038	0.437	0.267	4.513	0.034	0.077
	30	0.032	0.622	0.448	30.109	0.222	0.045
	40	0.044	0.819	0.432	44.359	0.324	0.056
	50	0.037	0.569	0.381	32.075	0.331	0.049
St. 1	0	0.027	0.493	0.289	5.731	0.029	0.124
27 August	10	0.047	0.617	0.660	10.334	0.045	0.051
	20	0.045	0.898	0.202	8.545	0.030	0.072
	30	0.044	1.092	0.636	14.303	0.191	0.148
	40	0.060	0.909	0.449	37.995	0.355	0.279
	50	0.048	1.948	0.542	96.524	0.383	0.144
St. 3	0	0.045	1.983	0.849	24.583	0.056	0.043
25 August	10	0.031	0.635	0.361	8.361	0.035	0.039
	20	0.047	0.624	0.267	6.931	0.048	0.097
	30	0.033	0.629	0.623	34.682	0.158	0.076
	40	0.050	0.861	0.423	41.092	0.317	0.042
	50	0.040	0.532	0.473	32.526	0.318	0.051
St. 3	0	0.039	0.584	0.470	10.432	0.034	0.104
27 August	10	0.049	0.595	0.335	4.822	0.025	0.052
	20	0.033	0.645	0.345	14.951	0.027	0.032
	30	0.031	0.503	0.236	12.196	0.162	0.072
	40	0.045	0.938	0.526	43.684	0.317	0.274
	50	0.067	0.482	0.513	32.119	0.297	0.199
Referencestation	0	0.048	0.633	0.235	4.164	0.033	0.045
	10	0.032	0.428	0.348	3.394	0.030	0.086
	20	0.039	0.530	0.612	6.131	0.033	0.027
	30	0.060	0.637	0.268	5.861	0.028	0.026
	50	0.060	1.283	0.558	53.684	0.046	0.041
Detection limit		***0.005***	***0.025***	***0.081***	***0.052***	***0.007***	***0.014***

Annex 3. Metal analysis of seaweed

Growing tips were analyzed. Results are in µg/g dry weight.

ID #	Species	Station	Pb	Zn
37936	*Fucus distichus*	St 2	1.61	34.74
37937	*Fucus distichus*	St 2	1.59	32.53
37938	*Fucus distichus*	St 3	1.07	22.20
37939	*Fucus distichus*	St 3	1.09	18.33
37940	*Fucus distichus*	St 5	1.57	24.95
37941	*Fucus distichus*	St 5	1.42	26.77
37942	*Fucus distichus*	St 6	0.77	21.18
37943	*Fucus vesiculosus*	St 10	3.38	95.14
37944	*Fucus vesiculosus*	St 10	3.32	117.81
37920	*Fucus vesiculosus*	St 12 Ø	7.62	205.42
37919	*Fucus vesiculosus*	St 12 Ø	9.75	270.28
37921	*Fucus vesiculosus*	St 12 SW	6.20	136.68
37922	*Fucus vesiculosus*	St 12 SW	6.05	151.18
37923	*Fucus vesiculosus*	St 15	4.40	152.82
37924	*Fucus vesiculosus*	St 15	3.75	146.73
37925	*Fucus distichus*	St 15A	1.93	62.01
37926	*Fucus distichus*	St 15A	2.60	80.09
37874	*Fucus vesiculosus*	St 17	3.51	79.43
37875	*Fucus vesiculosus*	St 17	3.36	80.23
37876	*Fucus vesiculosus*	St 17A	2.37	48.85
37877	*Fucus vesiculosus*	St 17A	1.97	48.44
37878	*Fucus vesiculosus*	St 17B	3.92	91.72
37879	*Fucus vesiculosus*	St 17B	4.26	85.87
37880	*Fucus vesiculosus*	St 17C	4.80	102.36
37881	*Fucus vesiculosus*	St 17C	4.03	91.61
37882	*Fucus vesiculosus*	St 22	1.59	36.04
37883	*Fucus vesiculosus*	St 22	1.63	36.52
37847	*Fucus vesiculosus*	St 25	1.11	29.43
37848	*Fucus vesiculosus*	St 25	1.29	29.39
37849	*Fucus vesiculosus*	St 29	1.71	43.66
37850	*Fucus vesiculosus*	St 29	1.80	40.60
37851	*Fucus vesiculosus*	St 30	1.92	41.04
37852	*Fucus vesiculosus*	St 30	1.64	34.72
37829	*Fucus vesiculosus*	St 33	0.73	17.35
37830	*Fucus vesiculosus*	St 33	0.71	19.30
37831	*Fucus vesiculosus*	St 36	1.04	24.93
37832	*Fucus vesiculosus*	St 36	1.17	25.14
37833	*Fucus distichus*	St 37	1.00	33.34
37834	*Fucus distichus*	St 37	1.13	29.25
37805	*Fucus vesiculosus*	St 38	0.64	12.14
37806	*Fucus vesiculosus*	St 38	0.60	13.20
37823	*Fucus distichus*	St F	0.49	8.64
37824	*Fucus distichus*	St F	0.54	9.28

37825	*Fucus distichus*	St V	0.52	9.94
37826	*Fucus distichus*	St V	0.53	10.30
37827	*Fucus distichus*	St G	0.68	13.31
37828	*Fucus distichus*	St G	0.55	12.06
37803	*Fucus vesiculosus*	St L	0.55	11.92
37804	*Fucus vesiculosus*	St L	0.43	11.66

Annex 4. Metal analysis of blue mussel

Soft tissue was analyzed. Results are in µg/g dry weight.

ID ¤	Station	Size group	Number of individuals	Mean individual weight (g wet weight)	Dry weight %	Pb	Zn
37945	St 2	5-6 cm	20	5.8	16.89	21.16	137
37946	St 2	6-7 cm	20	6.9	14.43	44.61	229
37947	St 3	5-6 cm	20	5.3	19.73	14.27	154
37948	St 3	6-7 cm	20	8.3	17.53	23.77	178
37949	St 5	5-6 cm	20	6.0	16.08	20.67	120
37950	St 5	6-7 cm	20	7.4	16.27	35.37	139
37951	St 6	5-6 cm	20	5.5	19.66	14,49	145
37952	St 6	6.0-7.7 cm	19	8.5	19.11	21.63	154
37953	St 10	5-6 cm	20	4.8	14.31	87.31	254
37954	St 10	6-7 cm	20	5.5	16.21	125.04	293
37929	St 12 SW	5-6 cm	20	5.2	12.22	154.79	386
37930	St 12 SW	6-7 cm	19	5.8	13.71	190.53	454
37931	St 12 SW	> 7 cm	17	11.8	12.27	277.26	601
37927	St 12 Ø	5-6 cm	20	5.2	15.07	151.89	429
37928	St 12 Ø	6-7 cm	20	7.7	15.22	218.76	508
37932	St 15	5-6 cm	20	4.4	12.98	110.08	314
37933	St 15	6-7 cm	20	5.8	14.22	90.21	233
37934	St 15A	5-6 cm	20	4.7	13.85	70.83	285
37935	St 15A	6-7 cm	20	5.7	14.93	83.60	267
37886	St 17	5-6 cm	20	4.7	16.31	32.88	177
37887	St 17	6-7 cm	20	6.7	15.35	43.00	156
37888	St 17A	5-6 cm	20	4.0	15.56	31.16	135
37889	St 17A	6-7 cm	20	4.6	19.49	34.35	156
37890	St 17B	5-6 cm	20	4.4	15.69	46.22	200
37891	St 17B	6-7 cm	20	5.1	22.10	45.02	187
37892	St 17C	5-6 cm	20	4.2	14.31	48.26	291
37893	St 17C	6-7 cm	20	5.7	15.59	62.44	294
37884	St 22	5-6 cm	20	3.2	16.02	33.58	171
37885	St 22	6-7 cm	20	5.6	16.26	39.67	179
37863	St 25	5-6 cm	20	5.9	14.68	21.25	212
37864	St 25	6-7 cm	20	3.8	13.41	17.89	146
37865	St 29	5-6 cm	20	3.8	12.84	21.76	151
37866	St 29	6-7 cm	20	5.3	14.41	28.81	177
37867	St 30	5-6 cm	20	3.6	12.49	25.87	174
37868	St 30	6-7 cm	20	5.1	13.39	29.34	154
37841	St 33	5-6 cm	20	3.7	13.27	5.90	160
37842	St 33	6-7 cm	19	5.9	13.82	7.78	153
37843	St 36	5-6 cm	20	3.8	11.66	16.17	150
37844	St 36	6-7 cm	20	4.8	13.46	16.20	154
37845	St 37	5-6 cm	20	3.8	14.68	6.39	114
37846	St 37	6-7 cm	19	5.4	15.34	6.67	141

37839	St 38	5-6 cm	20	4.6	13.92	3.65	159
37840	St 38	6-7 cm	20	6.7	14.24	4.73	162
37836	St F	6.0-7.9 cm	19	10.7	16.75	2.87	113
37837	St G	5-6 cm	18	5.3	15.95	2.61	115
37838	St G	6-7 cm	20	7.6	15.80	3.18	149
37801	St L	5-6 cm	20	4.5	16.46	1.64	135
37802	St L	6-7 cm	20	6.6	15.39	2.48	140
37835	St V	5.2-8.0 cm	6	11.7	19.08	2.58	100

Annex 5. Lead analysis of shorthorn sculpin

Results are in µg/g dry weight. Ref: reference site, YQ: Outer Qaamarujuk, IQ: Inner Qaamarujuk,

ID-No	Station	Length (cm)	Weight (g)	Sex	Tissue	Dry weight_%	Pb
37899	IQ	35	600	female	liver	35.75	0.207
37900	IQ	36	590	female	liver	33.51	0.460
37901	IQ	34	530	female	liver	31.55	0.051
37902	IQ	25	270	female	liver	33.9	0.419
37903	IQ	25	200	female	liver	42.86	0.224
37904	IQ	24	220	male	liver	43.65	0.300
37905	IQ	26.5	210	female	liver	42.23	0.130
37906	IQ	27	280	female	liver	37.5	0.413
37907	IQ	24.5	190	female	liver	40	0.545
37908	IQ	22.5	140	male	liver	40.31	0.184
37869	YQ	23.5	160	female	liver	27.42	0.146
37870	YQ	26	220	male	liver	43.03	0.675
37871	YQ	30	310	male	liver	37.22	0.081
37872	YQ	33	500	female	liver	35.78	0.159
37873	YQ	35	600	female	liver	28.19	0.156
37894	YQ	35	630	female	liver	37.11	0.028
37895	YQ	34.5	540	female	liver	33.73	0.202
37896	YQ	29.5	370	female	liver	32.64	0.113
37897	YQ	25.5	220	female	liver	32.72	0.079
37898	YQ	27	230	male	liver	36.57	0.325
37813	Ref.	25	170	male	liver	28.48	0.032
37814	Ref.	15.5	45	male	liver	32.72	0.040
37815	Ref.	20	80	male	liver	19.99	0.055
37817	Ref.	29	310	male	liver	25.36	0.063
37818	Ref.	31	360	female	liver	31.18	0.035
37819	Ref.	20.5	110	male	liver	18.64	0.064
37820	Ref.	2.5	130	female	liver	18.45	0.070
37821	Ref.	20	90	male	liver	25	0.052
37822	Ref.	17	60	female	liver	32.72	0.028
37899	IQ	35	600	female	muscle	18.78	0.194
37900	IQ	36	590	female	muscle	17.11	0.567
37901	IQ	34	530	female	muscle	18.01	0.056
37902	IQ	25	270	female	muscle	18.38	0.060
37903	IQ	25	200	female	muscle	19.61	0.046
37904	IQ	24	220	male	muscle	19.54	0.056
37905	IQ	26.5	210	female	muscle	21.39	0.061
37906	IQ	27	280	female	muscle	18.4	0.125
37907	IQ	24.5	190	female	muscle	19.05	0.068
37908	IQ	22.5	140	male	muscle	18.31	0.096

In livers ID# 37814, 37822 and 37897 there was too little material to also determine the dry weight percentage. In these cases the mean dry weight percentage of all liver samples (32.72%) has been used to calculate the lead concentrations on a dry weight basis.

Annex 6. Lead analysis of Northern prawn

Results are in µg/g dry weight. Ref: reference site, YQ: Outer Qaamarujuk, IQ: Inner Qaamarujuk, H+S: heads and shells,

ID #	Area	Tissue	Length group	Number of individuals	Mean indivual weight (g)	Dry weight %	Pb µg/g dry weight
37808	Ref	H+S	15-20 mm	16	3.70	24.35	0.622
37810	Ref	H+S	20-25 mm	23	7.34	26.55	0.813
37812	Ref	H+S	25-32 mm	10	10.90	24.85	0.839
37854	YQ	H+S	20-22 mm	28	5.23	21.38	1.779
37856	YQ	H+S	22-24 mm	30	6.76	22.80	1.867
37858	YQ	H+S	24-26 mm	25	8.37	24.15	3.536
37860	YQ	H+S	26-28 mm	20	10.40	22.93	3.096
37862	YQ	H+S	>28 mm	9	13.05	22.48	2.326
37910	IQ	H+S	20-22 mm	28	4.95	22.64	1.894
37912	IQ	H+S	22-24 mm	25	6.84	24.30	1.892
37914	IQ	H+S	24-26 mm	25	8.34	24.19	2.345
37916	IQ	H+S	26-28 mm	11	10.00	23.41	2.071
37918	IQ	H+S	28-30 mm	2	12.43	20.74	1.328
37807	Ref	Meat	15-20 mm	16	3.70	20.35	0.055
37809	Ref	Meat	20-25 mm	23	7.34	21.59	0.065
37811	Ref	Meat	25-32 mm	10	10.90	21.03	0.088
37853	YQ	Meat	20-22 mm	28	5.23	20.22	0.146
37855	YQ	Meat	22-24 mm	30	6.76	20.44	0.138
37857	YQ	Meat	24-26 mm	25	8.37	20.81	0.137
37859	YQ	Meat	26-28 mm	20	10.40	20.36	0.159
37861	YQ	Meat	>28 mm	9	13.05	20.12	0.144
37909	IQ	Meat	20-22 mm	28	4.95	20.45	0.243
37911	IQ	Meat	22-24 mm	25	6.84	20.67	0.182
37913	IQ	Meat	24-26 mm	25	8.34	20.48	0.156
37915	IQ	Meat	26-28 mm	11	10.00	20.36	0.131
37917	IQ	Meat	28-30 mm	2	12.43	18.05	0.102

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The environmental studies conducted in 2007 show that pollution sources still exist at Maarmorilik 17 years after mine closure in 1990. We can still see elevated lead and zinc levels in the environment. However, over a number of years lead and zinc levels in seawater and biota have decreased, in particular after the mine closed, and the area affected by pollution with lead and zinc has become smaller and smaller over the years. It is now primarily in Affarlikassaa and Qaamarujuk, an impact can be seen.

684 Environmental monitoring at the lead-zinc mine in Maarmorilik, Northwest Greenland, 2007

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