ENVIRONMENTAL MONITORING AT THE FORMER LEAD-ZINC MINE IN MAARMORILIK, NORTHWEST GREENLAND, IN 2008

NERI Technical Report no. 737 2009

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Doris Schiedek
Gert Asmund
Poul Johansen
Frank Rigét
Kasper Johansen
Jacob Strand
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Data sheet

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Authors:	Doris Schiedek[1], Gert Asmund[1], Poul Johansen[1], Frank Rigét[1], Kasper Johansen[1], Jacob Strand[2] & Stephan Mølvig[2]
Departments:	[1]Department of Arctic Environment [2]Department of Marine Ecology
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Abstract: The environmental studies conducted in 2008 show that pollution sources still exist at Maarmorilik 18 years after mine closure in 1990. Elevated lead and zinc levels are still found 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 the fjords Affarlikassaa and Qaamarujuk an impact can be seen.

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Summary

From 1973 to 1990 lead and zinc ore was mined at Maarmorilik in the municipality of Uummannaq 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 Affarlikassaa fjord to a processing plant in Maarmorilik. The produced lead and a zinc concentrate was loaded on ships and transported to smelters in Europe.

During mining different sources of pollution were identified. Ore crushing and transport of concentrate created dust that was dispersed into the environment. Waste rock dumps were another source for dust but also for the release of lead and zinc to the aquatic environment (e.g. the surrounding fjords). The most important pollutant source, however, were the mine tailings that were discharged into the Affarlikassaa fjord and settled there. In addition, after mine closure, a waste rock dump was excavated and dumped into the Affarlikassaa Fjord on top of the tailings.

Since 1972, environmental studies have been conducted in the vicinity of the mine and the fjords around Maarmorilik by monitoring lead and zinc content in seawater, sediments and biota (seaweed, mussels, fish, prawns and lichens). This report presents and assesses the results of the environmental studies conducted in 2008 as well as temporal trends based on the data collected since 1972.

The lead and zinc dispersal with dust around Maarmorilik has been monitored using the lichen *Cetraria nivalis*. It is a good indicator for dispersal of metals in the atmosphere, since it takes up water, nutrients and contaminants solely via its surface. Lichens, transplanted in 2007 from a reference site to locations near Maarmorilik showed in 2008 increased levels of lead and zinc. Clearly elevated lead concentrations were found in lichens from Affarlikassaa, Qaamarujuk and Qeqertanguit with levels between about 2 to 10 µg/g dry weight above background. Zinc concentrations were not elevated to as high levels as lead and were elevated only within a short distance from Maarmorilik. There is no indication that dusting with lead and zinc has changed since 1996, when we introduced a study to evaluate temporal changes.

During mine operation, lead and zinc concentrations in the Affarlikassaa fjord were high, particularly in the bottom water, mainly due to the discharged tailings. After mine closure, metal concentrations in the water have declined significantly. Since 1995, lead concentration has been about 1000 times lower than in 1988-89 during mining. This was also the case in 2008. Zinc concentrations have also decreased but to a lower degree and were in 2008 only about 8 times lower than in 1988-1989.

Seaweeds (*Fucus vesiculosus* and *Fucus distichus*) are common in the tidal zone and known to take up metals from the surrounding water and to be a good indicator of metal pollution. Seaweeds have been monitored since 1981 and their lead and zinc concentrations have decreased significantly, especially after mine closure (lead more than zinc). However, in 2008

lead and zinc concentrations are still elevated in seaweed from Affarlikassaa, Qaamarujuk and the northern coast of Perlerfiup kangerlua.

Blue mussels are suited to monitor metal pollution since they take up and accumulate metals from seawater, sediments and organic particles. Lead and zinc concentrations in blue mussels have declined significantly after mine closure, but lead levels only slowly, because the mussels cannot eliminate all the lead accumulated in the tissues. In 2008 lead concentrations were elevated in all of the studied fjords: Affarlikassaa, Qaamarujuk and Perlerfiup kangerlua. Zinc concentrations were elevated in a smaller area. Until 2005 the lead concentration in blue mussels was so high, that people were advised not to collect and eat blue mussels from these fjords. Studies conducted since 2005 show that the lead contamination of blue mussels has declined significantly, and the area with restrictions has been narrowed down to Affarlikassaa, Qaamarujuk and the area west of here.

Shorthorn sculpin (*Myoxocephalus scorpius*) is a common, rather stationary fish species, and therefore suited as indicator of metal contamination in fish. In both liver and bone tissue the lead concentration has decreased over the monitoring period. In 2008, lead concentrations were not elevated in muscle tissue compared to the reference site. Generally, concentrations are decreasing towards levels close to those found at the reference station, but they are still elevated (c. by factor of about 2).

Northern shrimp (*Pandalus borealis*) is another useful indicator to assess spatial and temporal trends of lead contamination. Over the monitoring period, lead concentrations have decreased in shrimps (head, shells and meat). In 2008, lead concentrations were slightly elevated.

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 in 2008 were below guidelines set to protect human health.

Overall conclusion

The environmental studies conducted in 2008 document that the fjords at Maarmorilik are still affected by pollution 18 years after mine closure. 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. Now an impact can be seen primarily in the Affarlikassaa and Qaamarujuk fjords.

Tailings and waste rock deposited on the bottom of the Affarlikassaa fjord are still a source of zinc release to the bottom water of the fjord. Waste rock dumps left on the slopes of the Black Angel Mountain are also a main pollution source of lead and zinc not only for the aquatic environment but also for dust dispersal to the terrestrial environment.

Eqikkaaneq

Maarmorilimmi Uummannap kommuniani ittumi aatsitassarsioqatigiiffik Greenex A/S 1973-imiit 1990-imut aqerlussamik zinkissamillu qalluinermik ingerlataqarpoq. Aqerlussaq zinkissarlu annermik nassaasaavoq qaqqami Inngili Qernertumik taaguutilimmi. Qaqqami tassani aatsitassaq 600 meterinik qatsissusilimmiit piiarneqarpoq Affarlikassaanullu silaannakkut ikaartaassuit atorlugit Maarmorilimmut suliarinneqarfissaanut aqqussorneqartarluni. Aqerloq zinkilu akuiakkat umiarsuarnut usiliussuunneqartarput Europamilu aatsiterivinnut ingerlanneqartarlutik.

Aatsitassarsiorfiup ingerlanerata nalaani mingutsitsineq qassiinik aallaaveqarpoq. Akuiagassap aserorterneqarneratigut akuiakkallu angallanneqarneratigut avatangiisit pujoralatserneqartarput. Aserorternerlukuttaaq pujoralatsitsisuusarput, aammali aqerlumik zinikimillu imermut taratsumullu seeritsisarlutik. Mingutsitsinerpaajuppulli akuiarnerlukut "tailings"-inik taaneqartartut Affarlikassaanut eqqarneqartartut immamullu kiviorartartut. Aatsitassarsiorfik matummat aserorternerlukut qallorneqarput Affarlikassaanilu akuiarnerlukut "tailingit" qaavinut iliorarneqarlutik.

Kangerlunni Maarmorillup eqqaaniittuni avatangiisit 1972-imiilli misissuiffigineqartarput taratsup, marraap, naasut uumasullu misissuagassanik katersuiffigisarnerisigut. Nalunaarusiami matumani saqqummiunneqarput misissuinernit 2008-imi ingerlanneqartunit paasisat, kiisalu avatangiisit tamaani qanoq issusii naliliiffigineqarputtaaq. Paasisat ukiuni siuliini paasisanut sanilliunneqartarput.

Aqerlup zinkillu aatsitassarsiorfimmiit pujoralatserinikkut siammarsimanerat misissorneqartarpoq tamatuma eqqaani qillinerit (ujaqqat naaneri) aqerlumik zinkimillu akoqarnerinik misissuiffigiumallugit katersortarnerisigut misissoqqissaartarnerisigullu. Naasut taakku pujoralaap nakkaanerinik uuttuutigineqarsinnaasarput qaamikkut silaannarmiit inuussutissamik taamaallaat piortortarnertik pissutigalugu. Qillinerit 2007-imi mingutsitaanngitsumiit Maarmorillup eqqaannut nuunneqartut 2008-imi aqerlumik zinkimillu akoqarnerulersimapput. Affarlikassaani, Qaamarujummi Qeqertannguanilu erseqqivissumik aqerlumik akoqalersimapput, tassa akoqanngitsunut naleqqiullutik grammimut 2 aamma 10 mikrogrammit akornanni akoqalersimasaramik. Zinkimik akui taama qaffasitsiginngillat Maarmorilimmullu qanittumi taamaallaat akoqarnerulersimallutik. Pujoralatsigut mingutsitsinerup allanngoriartornera paasilluarumallugu 1996-imiit qillinernik nuussisalernermiit allanngorsimaneranik malunnartoqanngilaq.

Aatsitassarsiorfiup ingerlagallarnerani Affarlikassaani imaq aqerlumik zinkimillu akulerujussuuvoq, pingaartumik immap naqqata ernga. Aatsitassarsiorfiup matunerata kingorna kangerluup erngata saffiugassamik akui annikilleriaqaat. 1995-imiit (aammattaaq 2008-imi) aqerloq 1988-89-imiit aatsitassarsiorfiup ingerlagallarnerata nalaaniit 1000-eriaammik annikinneruvoq. Zinkimik akoqarnera aamma annikinnerugaluartumik

annikilliartorpoq, 2008-imilu taamaallaat 1988-89-imit arfineq-pingasoriaammik annikinneruvoq.

Qeqqussat (equutit) (*Fucus vesiculosus* and *Fucus distichus*) ulluttagaani naasartut imermit avatangiisiminnit saffiugassanik tigooraasaramik immap mingutsinneqarsimaneranik uuttuinermut atorneqarsinnaapput. Qeqqussat 1981-imili misissuiffigineqartarput, piffissarlu misissuiffiusartoq (1981-2008) tamaat isigigaanni aqerlumik zinkimillu akoqassusiat appariartorsimavoq pingaartumik aatsitassarsiorfiup matuneqarnerata kingornagut, aqerloqassusiallu zinkeqarneraniit appariartoruvoq. 2008-imi Affarlikassaani, Perlerfiullu Kangerluata avannamut sineriaani Qaamarujummi aqerloq zinkilu qaffasipput.

Uillut ulluttagaaniittut immamiit taratsumik, uumassusilinnik sunillu mikisuaqqanik tigooraasaramik immap mingutsitaasimaneranik uuttuinermut atorneqarsinnaapput. Uillut aqerlumik zinkimillu akoqassusiat aatsitassarsiorfiup matunerata kingorna appariarsimaqaaq, aqerlortaqassusialli annikitsuinnarmik appariartorpoq uillut aqerloq tigoreersimasartik peerneq sapilertarmassuk. Uilluni 2008-imi katersorneqarsimasuni Affarlikassaaniittut, Qaamarujummiittut aammalu Perlerfiup Kangerluaniittut allanit qaffasinnerusumik aqerlortaqarput, Maarmoriliulli eqqaani piffimmi annikitsumi taamaallaat allanit annerusumik zinkitaqarlutik. Siusinnerusukkut uillut ima aqerlortaqartigigaluarput kangerlunni taaneqartuni nerineqannginnissaat siunnersuutigineqartarluni. 2005-imiilli misissuisarnerit takutittarmassuk mingutsitsineq assut annikilleriarsimasoq uilortortoqannginnissaanik siunnersuuteqarfiusut Affarlikassaanut, Qaamarujummut aammalu tamatuma kitinnguanut annikillineqarnissaa siunnersuutigineqarpoq.

Kanajoq nalinginnaasoq (*Myoxocephalus scorpius*) uninngaarnerusartuugami Maarmorillup eqqaani aalisakkat mingutsitaasimanerannik misissuisarnermi atorneqartarpoq. Saarngini tinguanilu aqerloq annikilliartorsimavoq, naleqqiussiuffiusunilli suli marloriaammik annerulluni. 2008-imi nerpiini aqerloq allanit annerusimanngilaq.

Raaja itisoormioq (*Pandalus borealis*) aqerlumik mingutsitsisisoqarsimaneranut aamma uuttuutaasinnaavoq. Qaamarujummi raajat nerpiini aammalu niaquini/qalipaani aqerloq piffissami misissuiffiusartumi kiisalu 2008-imi annikitsuinnaasimavoq.

Kangerlunni Maarmorillup eqqaaniittuni aqerlup qaffasinnera pissutigalugu inuit tamaani aalisakkanik allanillu nerisaqartartut aarlerisarput. 2008-imi misissuinerni aqerloq killigititanit annikinneruvoq uillut sumiiffinni taaneqartut eqqaasanngikkaanni.

Eqikkaalluni inerniliineq

2008-imi misissuinertigut takutinneqarpoq Maarmorillup eqqaani – aatsitassarsiorfip 1990-imi matuneraniit ukiut 18 qaangiunnerani – suli mingutsitsineqartoq avatangiisini aqerlup zinkillu allanit qaffasinneruneranik uuttuiffiusinnaasumik. Ukiulli arlallit isigigaanni mingutsitsineq ataatsimut isigalugu annikillisimaqaaq, pingaartumik aatsitassarsiorfiup 1990-imi matunerata kingorna, sumiiffiillu aqerlumik zinkimillu mingut-

sitaasimasut annikilliartuinnarput. Massakkut annermik Affarlikassaa Qaamarujullu sunnerneqarsimanerminnik takkuissaapput.

Aatsitassarsiorfimmiit eqqaakkat (akuiarnerlukut "tailings" aammalu aserorternerlukut "waste rock") Affarlikassaanut eqqarneqarsimasut suli kangerluup naqqata ernganik mingutsitsipput. Qaqqami Inngili Qernertumi aserorternerlukut qimanneqarsimasut kangerlummut seerinermikkut pujoralatsitsinermikkullu aamma aqerlumik zinkimillu mingutsitsisuupput.

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. Denne rapport præsenterer resultaterne af de undersøgelser, som blev udført i 2008 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 (*Cetraria nivalis*) 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. Laver, som i 2007 blev transplanteret fra et uforurenet område til områder ved Maarmorilik, havde i 2008 fået forhøjet bly- og zinkkoncentration. Der var tydeligt forhøjede blyværdier i laver fra Affarlikassaa, Qaamarujuk og Qeqertanguit med niveauer mellem ca. 2 og 10 µg/g tørvægt over baggrundsniveauet. Zinkkoncentrationerne var ikke forhøjet i samme grad og kun i kort afstand fra Maarmorilik. Der er ikke noget, der tyder på, at støvforureningen har ændret sig siden 1996, da transplantationsmetoden blev introduceret for bedre at kunne undersøge den tidsmæssige udvikling af forureningen.

Mens minedriften fandt sted, fandtes der høje bly- og zinkkoncentrationer i vandet i Affarlikassaa, specielt i fjordens bundvand. Efter minens lukning er metalkoncentrationerne i fjordvandet faldet betydeligt. Siden 1995 (og også i 2008) har blykoncentrationerne været omkring 1000 gange lavere end i 1988-89, mens der var minedrift. Zinkkoncentrationerne er også faldet, men i mindre grad og var i 2008 kun omkring 8 gange lavere end i 1988-89.

Brunalger (*Fucus vesiculosus* and *Fucus distichus*), som vokser i tidevandszonen, optager metaller fra det omgivende vand og kan derfor anvendes til at måle forureningen af havvandet. Brunalgerne er blevet undersøgt siden 1981, og set over hele overvågningsperioden (1981-2008) er både bly- og zinkkoncentrationen i tang faldet, specielt efter minens luk-

ning, og blykoncentrationen er faldet mere end zinkkoncentrationen. I 2008 var der forhøjede bly- og zinkværdier i Affarlikassaa, i Qaamarujuk 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. Bly- og zinkkoncentrationen i blåmuslinger er faldet betydeligt efter minens lukning, men blykoncentrationen kun langsomt, fordi muslingerne ikke kan udskille alt det bly, de én gang har optaget. I blåmuslinger indsamlet i 2008 var 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 de nævnte fjorde. Men da undersøgelserne siden 2005 har vist, at forureningen er faldet væsentligt, foreslås dette område indskrænket til Affarlikassaa, Qaamarujuk og området umiddelbart vest herfor.

Almindelig ulk (*Myoxocephalus scorpius*) anvendes til at overvåge forureningen af fisk i området ved Maarmorilik, da den er ret stationær. I ben- og levervæv har blykoncentrationen været faldende, men er stadig ca. 2 gange højere end i referenceområder. I 2008 var der ikke forhøjet blykoncentration i muskelvæv.

Dybhavsreje (*Pandalus borealis*) er en anden anvendelig indikatorart for blyforurening. I rejer fra Qaamarujuk er blyforureningen i kød og hoveder/skaller faldet i løbet af overvågningsperioden og i 2008 var rejerne kun lidt forurenet med bly.

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 2008 er blyindholdet under gældende grænseværdier, bortset fra blåmuslinger i området nævnt ovenfor.

Sammenfattende konklusion

Undersøgelserne i 2008 viser, at der i Maarmorilik-området fortsat – 18 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.

Mineaffald ("tailings" og "waste rock") deponeret på bunden af Affarlikassaa er stadig en kilde til zinkforurening af fjordens bundvand. Dumpe af "waste rock" efterladt på Sorte Engel Fjeldet er også kilder til forurening med bly og zink, både som udvaskning til fjordene og som støvspredning.

1 Introduction

From 1973 to 1990, zinc and lead ore was mined at Maarmorilik in Northwest Greenland, in the inner part of a large fjord system. The closest community, Ukkussissat, is about 25 km to the west. The main town, Uummannaq, is about 80 km away 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 Affarlikassaa fjord 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.

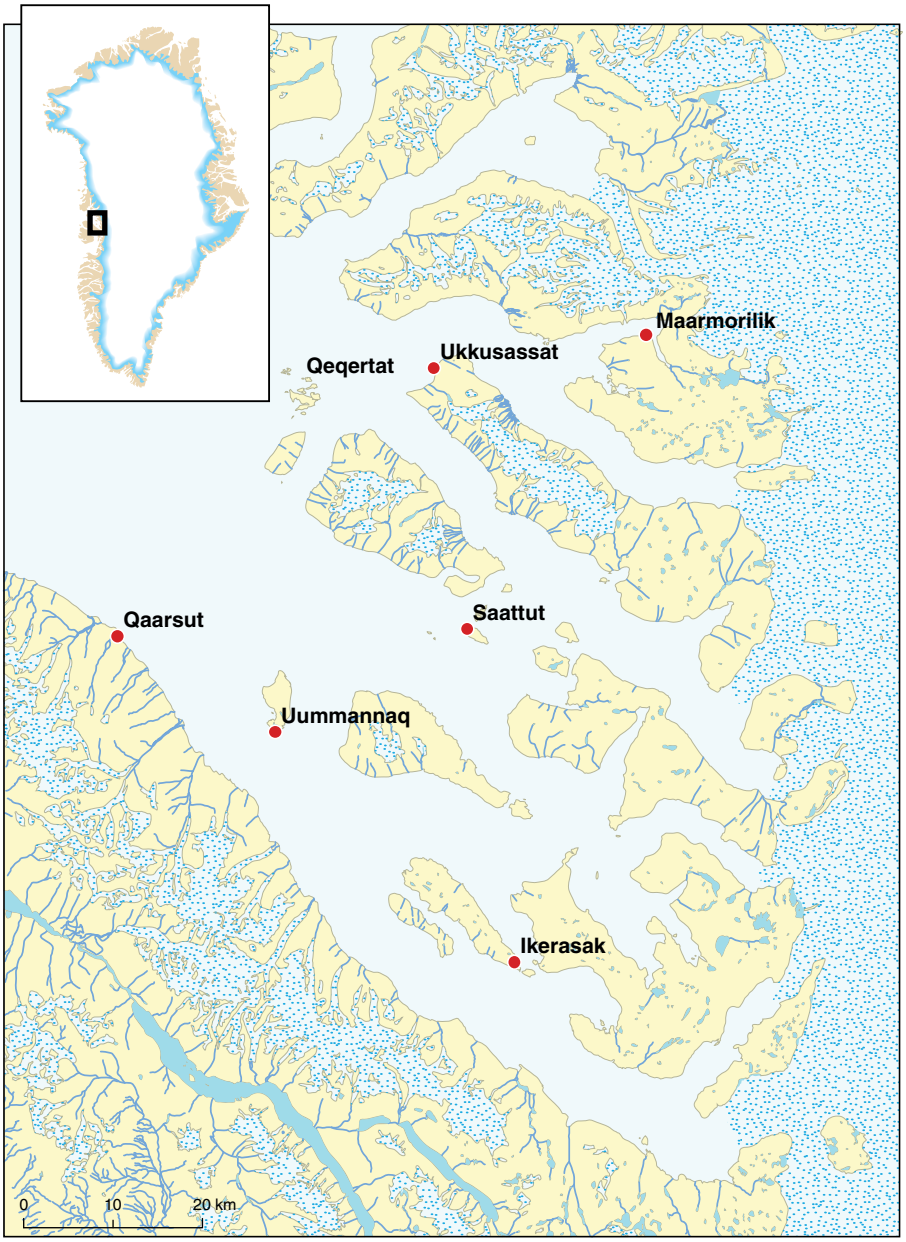


Figure 1.1. Location of the Maarmorilik mine (Northwest Greenland) and nearby settlements.

Tailings resulting from processing the ore were discharged into the Affarlikassaa fjord, where they settled. During the operation of the mine, several tons of lead and zinc where discharged annually into the fjord, leading to a serious pollution of the marine environment. A second pollution source was the dispersal of dust due to the ore crushing and handling of concentrates. A third important source for pollution was waste rock left on the steep slopes of the mountains. These waste rock dumps contained several hundred thousand tons of rock and elevated concentrations of lead and zinc. One of these dumps, "The Old Waste Rock Dump" was in particular polluting the sea with lead and zinc. In the summer 1990 this dump was removed as far as possible and the remains were dumped into the Affarlikassaa fjord on top of the tailings.

The pollution from the mining operation was monitored while mining took place and continued after mine closure. The monitoring comprises regular (in most of the years annually) sampling and chemical analysis of seawater and biota (seaweed, mussels, fish, prawns and lichens) and with longer intervals marine sediments and the benthic fauna (Johansen et al. 2006, Josefson et al. 2008). The most recent results of the regular monitoring carried out in 2007 were published by Johansen et al. (2008). The present report presents results from field work carried out in 2008.

2 Sampling

Sampling was carried out from 27August to 1 September 2008 with the fishery boat Nana L. Gert Asmund, Lene Bruun, Sigga Joensen and Doris Schiedek from NERI carried out the field work together with the ship's crew.

Samples of lichens (*Cetraria nivalis*) were collected at the fjords Affarlikassaa, Qaamarujuk and Perlerfiup Kangerlua and on the islands Qeqertat and Saatut (Fig 1.1 and 2.1 and Annex 1). To assess year to year variations of the air quality, in 2007 lichens were transplanted from Saatut, which is known to be unaffected by pollution from the mining operation, to different monitoring stations in the Affarlikassaa, Qaamarujuk and Perlerfiup Kangerlua and on the islands Qeqertat. In 2008, lichens from these stations (in total 12) were sampled as well as from the reference site (Saatut). Only fresh living lichens growing on dead organic matter were collected in order to ensure that the metals accumulated in the lichens originate solely from uptake via air and not from the underlying rocks. Samples were kept in paper bags.

Seawater samples were taken at stations 1 and 3 (Affarlikassaa fjord) and at a reference station in Uummannaq (Figure 1.1 and 2.1 and Annex 2), using a reversible Hydrobios water sampler, and filtered through a 0.45 µm polycarbonate filter. Afterwards, suprapure nitric acid (1ml/litre) was added.

Growing tips of seaweed (*Fucus vesiculosus* or *Fucus distichus*) were collected at 25 stations in the Affarlikassaa, Qaamarujuk, Perlerfiup Kangerlua fjords and at Qeqertat (Figure 1.1 and 2.1 and Annex 3). Samples were rinsed in demineralised water (3 times) and deep-frozen in polyethylene bags. At each station, 2 seaweed samples were collected in a distance of 10 to 30 metres in order to account for local variations. In the subsequent analyses and presentation of the results, the geometric mean concentration at each station has been used.

Blue mussels (*Mytilus edulis*) were collected at 26 stations in the Affarlikassaa, Qaamarujuk, Perlerfiup Kangerlua fjords and at Qeqertat (Figure 1.1 and 2.1 and Annex 4). Blue mussels collected at each station were divided into two or three size classes according to their shell length: 4-5 cm, 5-6 cm and 6-7 cm. 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.

Shorthorn sculpin (*Myoxocephalus scorpius*) was caught in three areas: the inner (IQ) and outer part (YQ) of Qaamarujuk fjord, and at a reference site (Ref) at Qeqertat (Figure 1.1, Figure 2.1 and Annex 5). Sex, length and weight of the fish were recorded. Liver and muscle samples for lead analyses were frozen in polyethylene bags.

Northern shrimp (*Pandalus borealis*) was caught in three areas: the inner part of Qaamarujuk (IQ), the outer part of this fjord (YQ) and at a reference site (Ref) at Qeqertat (Figure 1.1, 2.1 and Annex 6). The prawns were caught using a bottom dredge fitted with a fine mesh and divided into length groups. For each group, two types of samples were obtained: 1. the meat, 2. the remaining parts (heads and shells). All samples were kept in plastic bags and deep-frozen.

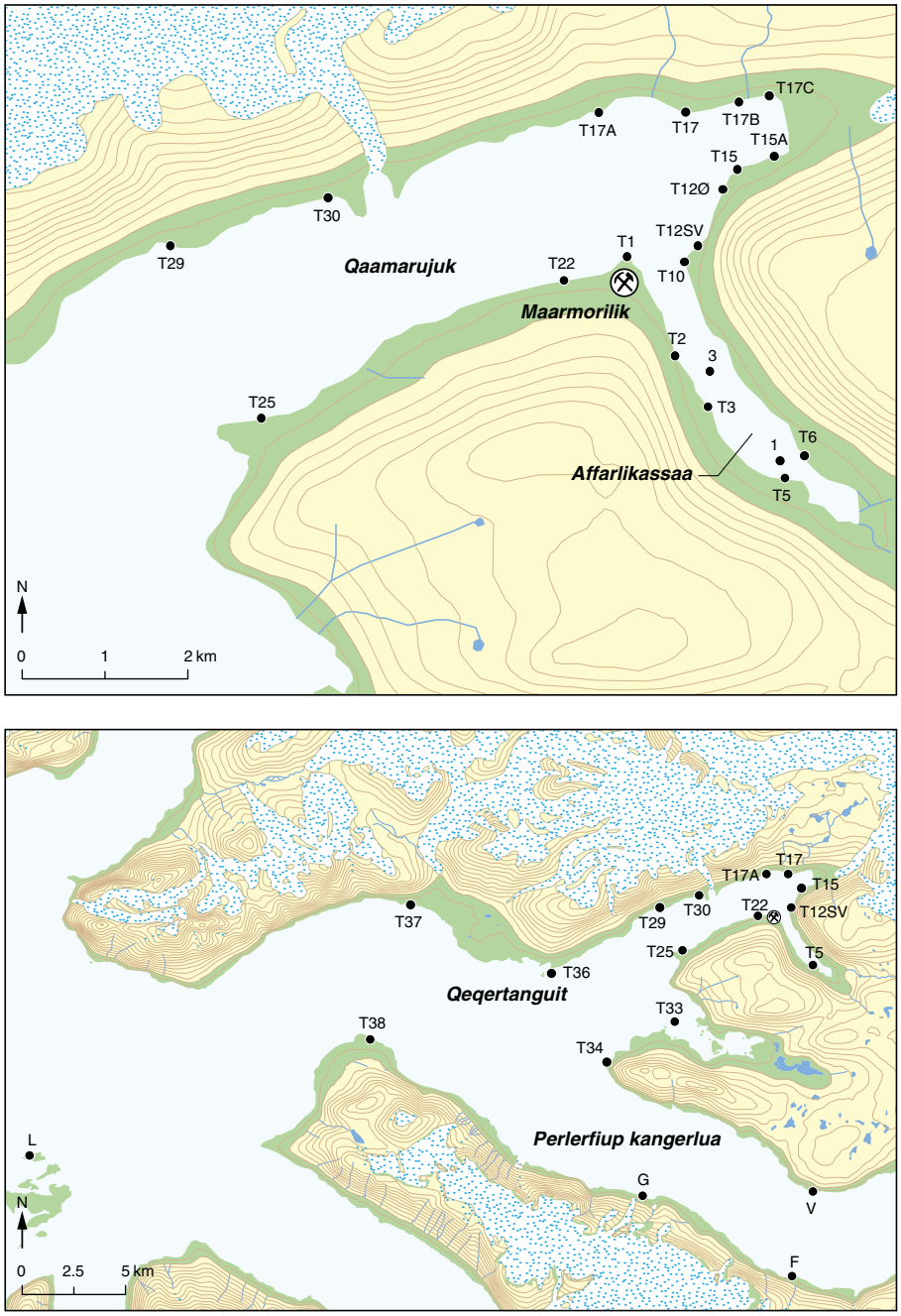


Figure 2.1. Sampling stations close to Maarmorilik (upper map)) and further away (lower map). Numbers 1 and 3 refer to the seawater sampling stations. Letters (with and without number) indicate sampling stations for lichens, seaweed and blue mussels.

3 Analytical methods and quality control

3.1 Seawater

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

The metal analyses were performed by an ICP-MS after online collection and desorbing on a Chelex ion exchanger and pH adjustment 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), all seaweed, mussel and prawn samples 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, to remove all foreign material, and subsequently dried at 60ºC for 24 hours.

For the analysis of the fish samples, a sub sample of c. 1 g of either liver or muscle was cut with a stainless steel blade, to avoid contamination from the exposed parts of the 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 105º C until constant weight.

A 0.3 g sub sample of the freeze-dried samples or 1 g fresh fish sample was 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 the uncertainty for the results obtained it too high. The detection limit depends on the method used, the pre-treatment and dilution of the samples. The detection limit applied 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 0.1 µg/g dry matter for lead and 4 µg/g dry matter for zinc.

3.4 Quality control

3.4.1 Biological samples

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.

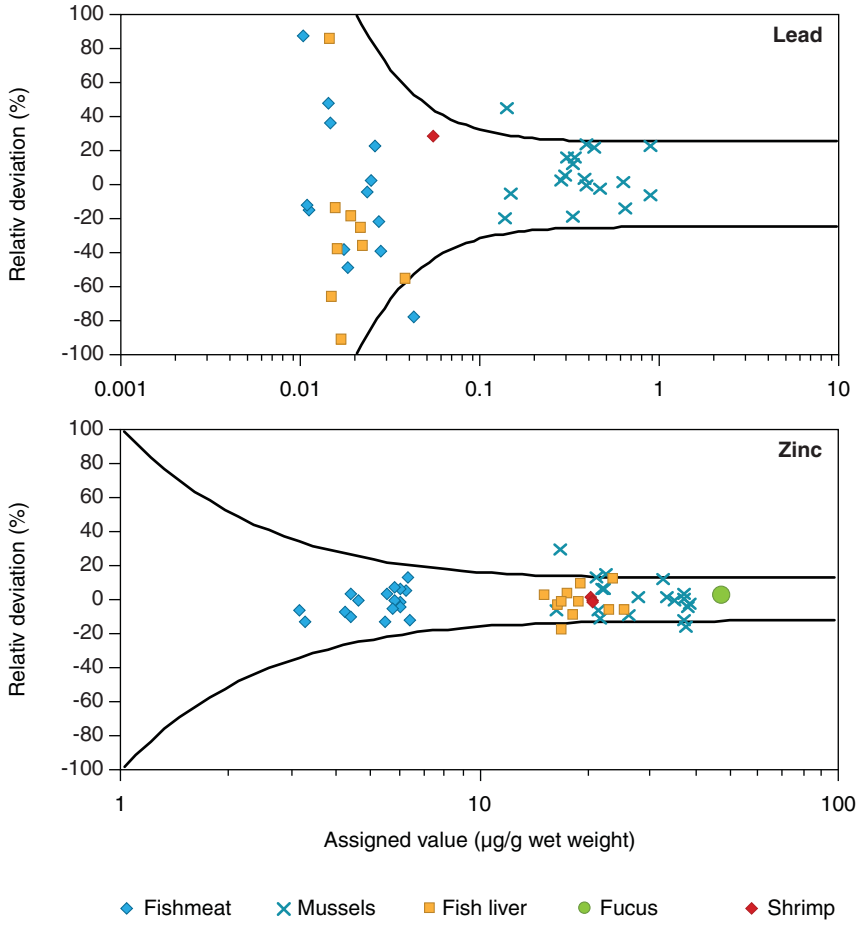


Figure 3.1. Results for lead (upper graph) and zinc (lower graph) from NERI-DAE's participitation in the QUASIMEME laboratory study programme. The lines represent the 95% confidence limit.

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 lines in Figure 3.1 represents the 95% confidence limits calculated as the sum-uncertainty of the detection limit and the relative uncertainty seen in the table below:

	Zinc	Lead
Constant error (detection limit), mg/kg wet weight	0.8	0.02
Proportional error (%)	12.5	25

Finally the analytical methods were checked by analyzing the same sample twice (same ID# but different nitric acid digestions). In this study, 8 samples were analyzed twice for zinc and 13 samples for lead. The average of the relative deviation was 12% for lead and 5.4% for zinc. The high relative deviation for lead is caused by one sample having low lead concentrations, making the lead analysis more uncertain (cf. Figure 3.1). It would be 7.1% with this sample omitted. When a sample has been analyzed twice, we have used the average in further calculations.

3.4.2 Seawater

The quality of seawater analyses was checked by analysing several old 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.

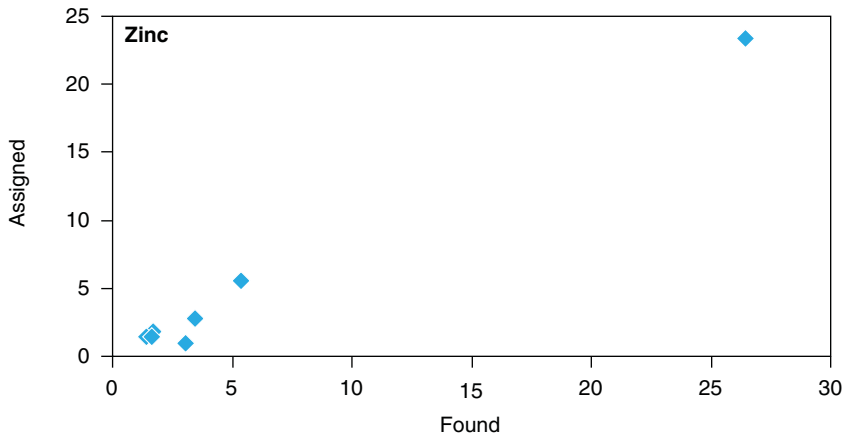
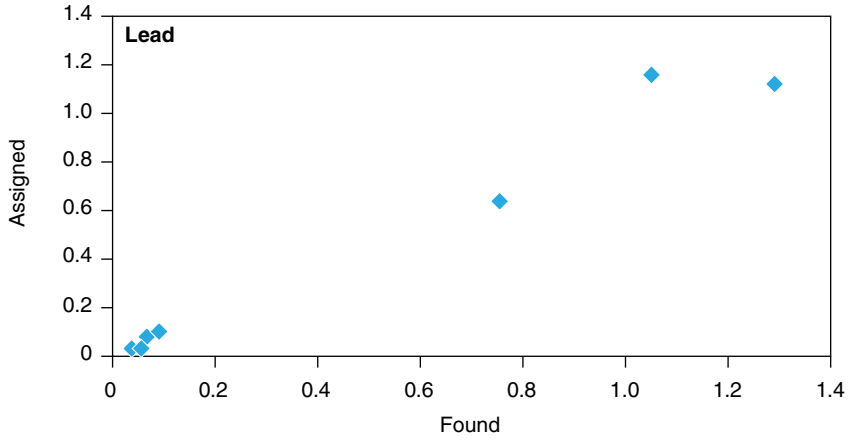


Figure 3.2. Comparison of analytical results with assigned values for zinc, µg/L.

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



Simultaneously with the samples from Maarmorilik NERI participated in round 55 of the QUASIMEME scheme, with the following results showing that there is very good agreement between found and assigned values.

Sample	Zinc assigned	Zinc found	Lead assigned	Lead found
QTM133SW	10.8	9.11	0.894	0.800
QTM134SW	10.9	9.235	1.33	1.186
QTM135SW	4.611	3.835	0.877	0.734

4 Results and discussion

In this section the results for the analysis of lichens, seawater, seaweed, mussels, fish and prawns are presented.

4.1 Lichens

Lichens are known to accumulate atmospheric pollutants and are abundant in the Arctic environment. The lack of roots, a large surface area and a long life span enable them to effectively bioaccumulate air contaminants. In many studies it has been shown that lichens are good indicators for various kinds of air pollution including those caused by mining activities (Naeth & Wilkinson, 2008).

The lichen species *Cetraria nivalis* is common in Greenland and thus suited as an indicator of metal pollution via the atmosphere. The species grows primarily on dead organic matter and takes up nutrients (and contaminants) exclusively from its surface. Once accumulated in the lichens, metals are only released from the plants at a very slow rate – if at all.

At Maarmorilik, the dispersal of metals via the atmosphere has been monitored over many years by sampling lichens at a number of stations close to the mine and in the region to the west. To assess year to year variations of the air quality lichens were collected at Saatut (Fig. 1.1) and transplanted to different locations at Maarmorilik and further away in 2007. In 2008 – after one year of transplantation – lichens were collected again and analyzed for lead and zinc. The results are shown in Annex 1 and the spatial trends are illustrated in Figures 4.1 – 4.2.

4.1.1 Spatial trends

Clearly elevated lead concentrations were found in lichens from Affarlikassaa, Qaamarujuk and Qeqertanguit with levels between 2 to 10 times higher than background level. The highest concentrations were found in lichens from T12SW at the "foot" of the Black Angel Mountain, were the old waste rock dump was located (Fig. 4.1 and 4.2). Lead concentrations were as high as in resident lichens analyzed in 2007 (Johansen et al. 2008). This indicates that the main sources of dust dispersal still are the waste rock dumps and their remains left on the slopes of the Black Angel Mountain. The Maarmorilik area itself also appears to be a source. Zinc concentrations were not elevated as much as lead and only within a short distance (2-3 km) from Maarmorilik.

In the lichens collected at Saatut and on Qeqertat, concentrations are low and in the same range as found in other areas in Greenland unaffected by local sources. At reference sites, used to the monitor the impact of mining activities at Nalunaq, Seqi and Maarmorilik, concentrations between 0.3-1 µg/g lead and 9-18 µg/g zinc were found in *Cetraria nivalis* (Glahder et al. 2009, Asmund et al. 2009, Johansen et al. 2006).

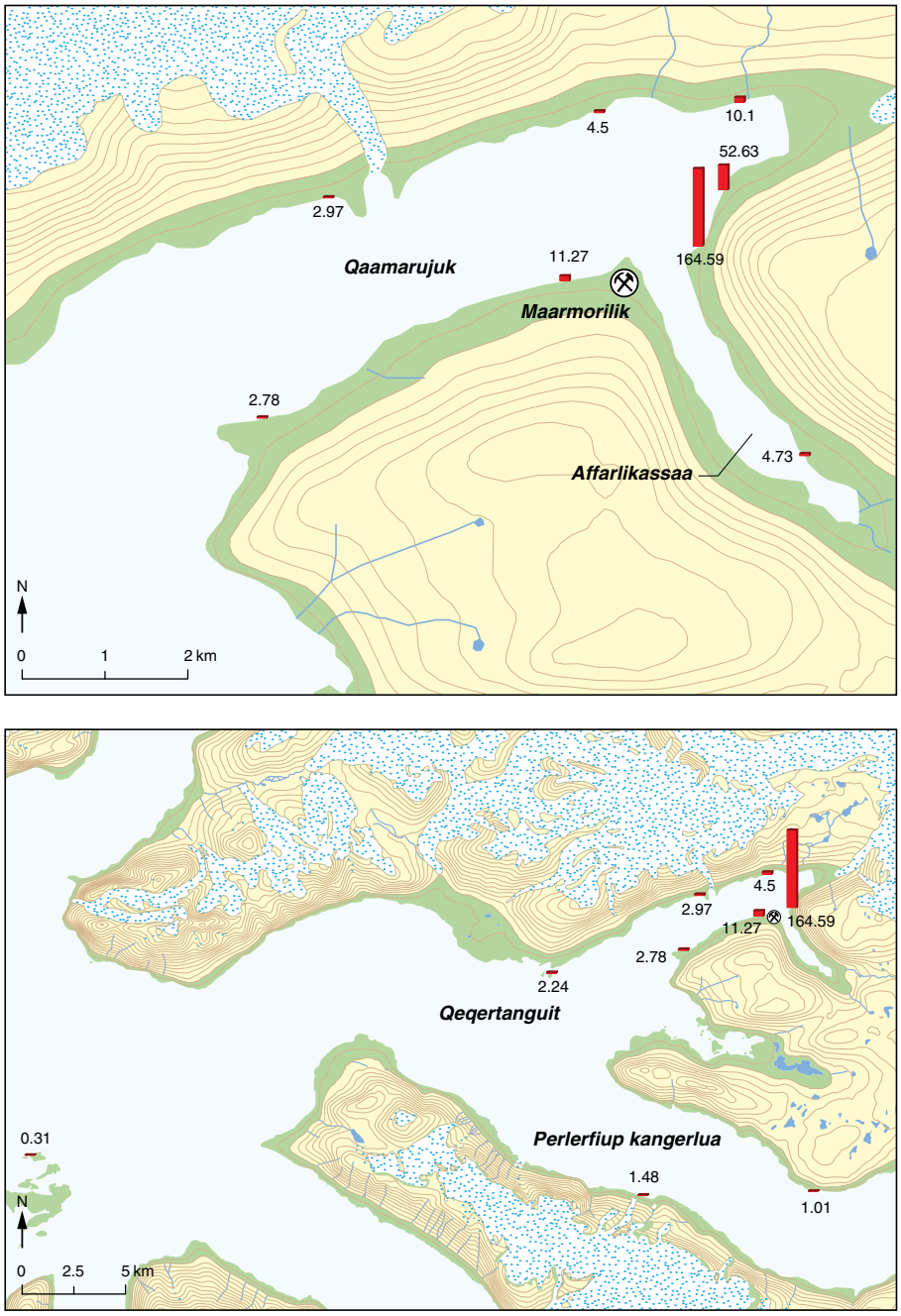


Figure 4.1. Lead concentrations (µg/g dry weight) in lichens (*Cetraria nivalis*) from sampling stations close to Maarmorilik (upper graph and further away (lower graph). The location of Saatut is shown in Figure 1.1.

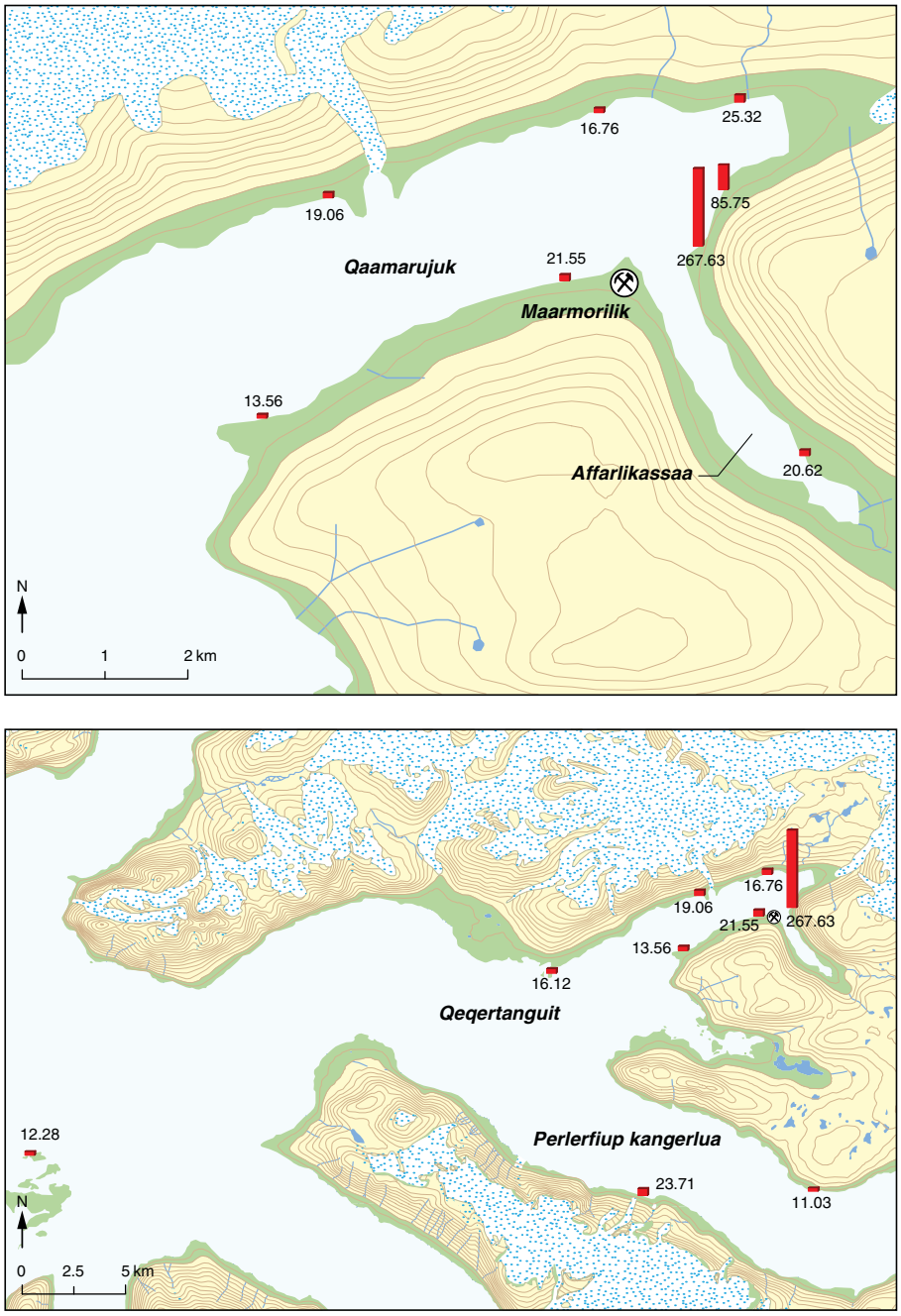


Figure 4.2. Zinc concentrations (µg/g dry weight) in lichens (*Cetraria nivalis*) from sampling stations close to Maarmorilik (upper graph) and further away (lower graph). The location of Saatut is shown in Figure 1.1.

4.1.2 Temporal trends

Since 1996 lichens have been transplanted from a reference site to different sites in Affarlikassaa, Qaamarujuk, Perlerfiup kangerlua and Qeqertat and left for one year (except in 2002, when they had been left for two years) before being sampled and analyzed. The results are summarized in Table 4.1.

No systematic apparent temporal trend (increasing or decreasing) was found at any of the sites. Lead levels were varying by a factor of 2 to 10 at the same site; variations were highest closest to Maarmorilik. The zinc levels varied less. The large variations are probably a result of inter-annual differences in wind patterns and other climatic parameters.

Table 4.1. Metal concentrations (µg/g dry weight) in lichen *Cetraria nivalis* at different sites (see Figure 2.1) one year after transplantation, respectively 2 years (2005).

	Pb					Zn				
Site	**1997**	**1999**	**2002**	**2005**	**2008**	**1997**	**1999**	**2002**	**2005**	**2008**
L	0.35	0.26	0.38	0.32	0.31	6.88	10.6	10.9	11.5	12.3
V	0.63	0.32	0.35	0.30	1.01	10.1	6.57	15.8	10.0	11.0
G	0.23	0.32	0.53	0.31	1.48	14.3	16.9	13.5	14.6	23.7
T6	3.23	1.09	2.42	10.3	4.73	16.2	14.5	22.2	21.4	20.6
T12SVW	89.2	27.9	80.4	110	165	146	79.5	51.1	176	268
T12Ø	18.2	16.4	17.3	51	52.6	35.8	61.4	29.7	96.3	85.8
T17A	3.91	4.28	5.01	1.86	4.50	19.1	22.6	17.7	16.5	16.8
T17B	7.68	11.4	19.8	10.0	10.1	19.0	72.6	28.6	34.1	25.3
T22	7.62	4.03	35.6	7.53	11.3	21.0	21.3	40.2	23.1	21.6
T25	1.89	1.75	1.34	0.76	2.78	13.7	18.7	14.4	5.80	13.6
T30	2.93	2.80	2.33	0.94	2.97	16.6	18.5	11.4	12.7	19.1
T36	2.12	1.28	1.98	0.81	2.24	14.1	18.7	10.1	9.80	16.1

4.2 Seawater

As part of the environmental monitoring during mine operation, seawater samples were regularly collected in the Affarlikassaa and Qaamarujuk fjords and analyzed for lead, cadmium and zinc. Tailings were discharged into the Affarlikassaa fjord at c. 30 meters depth. Increased lead and zinc concentrations were found in the water column. Particularly the water below 30 meters down to the seafloor of Affarlikassaa was heavily polluted. The environmental monitoring also documented that the lead and zinc pollution spread into the neighboring fjords.

4.2.1 Spatial trends

A study conducted in 1995 revealed that the metal concentrations in the water outside the Affarlikassaa fjord was below detection limit. Monitoring activities were adapted accordingly and seawater samples were therefore only taken in the Affarlikassaa fjord and at a reference station.

In 2008 samples were taken on 28 and 30 August at two stations in the Affarlikassaa fjord and at a reference station near Uummannaq. The results are shown in Annex 2 and illustrated in Figures 4.3, 4.4 and 4.5.

Figure 4.3. Zinc concentrations (µg/L) in the Affarlikassaa fjord in relation to water depth in August 2008.

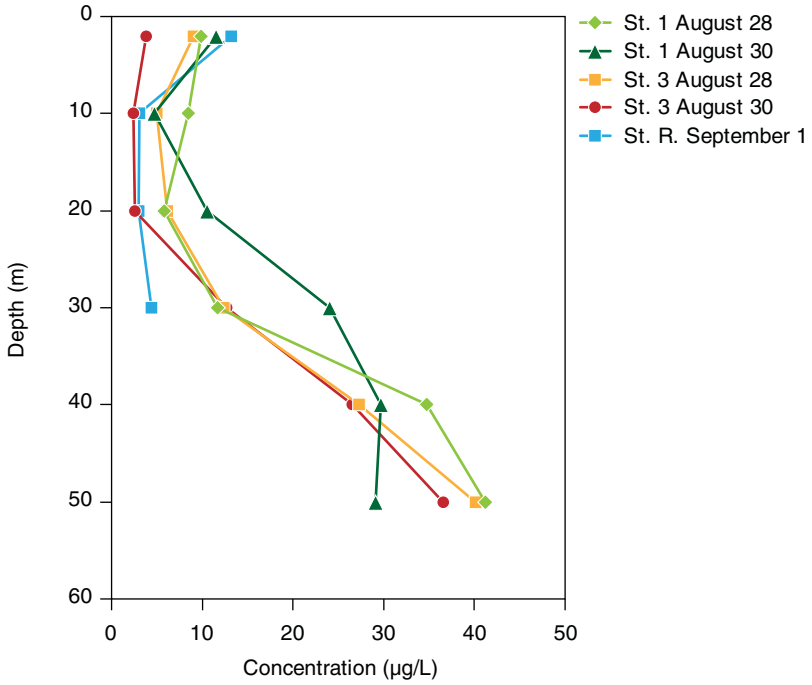
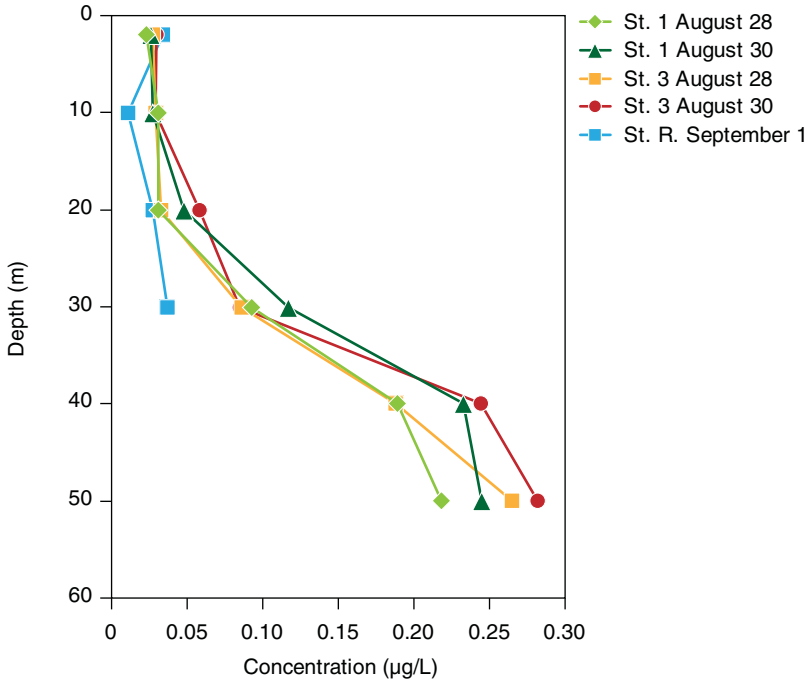


Figure 4.4. Cadmium concentrations (µg/L) in the Affarlikassaa fjord in relation to water depth.



In Figure 4.3 and 4.4 the zinc and cadmium concentrations are plotted against water depth. Møller (1984) has shown for the Affarlikassaa fjord that during summer a pycnocline (i.e. water bodies with different temperatures and salinity) is formed at about 25 metres water depth, which corresponds to the depth of the sill at the mouth of the fjord. As a result, zinc and cadmium concentrations are clearly elevated in the water mass below the sill (30-50 m) compared to the reference, whereas above the sill this is not the case.

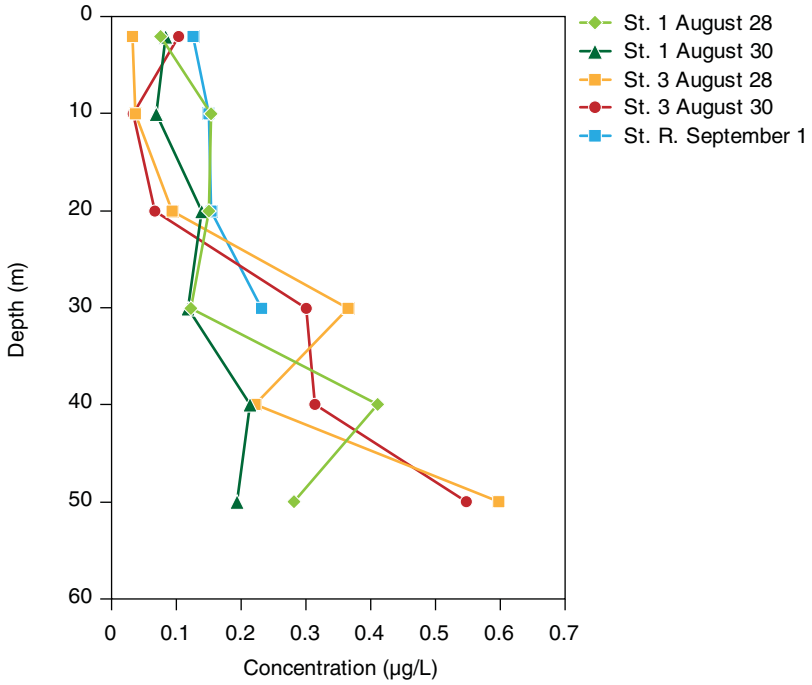


Figure 4.5. Lead concentrations (µg/L) in the Affarlikassaa fjord in relation to water depth.

A similar but not as clear picture was seen for lead (Fig. 4.5). There is a tendency of higher concentrations in the deeper part of the fjord than in the upper water column compared to the reference station. The lead concentration appears to be slightly elevated in the bottom water; app. 2 to 4 times the level measured in the upper 20 metres and in water taken at the reference station, but it is not consistent for all samples.

This documents that the tailings and the waste rock deposited on the bottom of the Affarlikassaa fjord are still a source of zinc, and to a minor degree also lead. This has also been shown in previous studies performed after mine closure. However, levels are now much lower than during mining (see below).

4.2.2 Temporal trends

While mining took place, the seawater below the pycnocline was heavily polluted by lead, cadmium and zinc in summer and fall, whereas above the pycnocline lead and zinc concentrations were much lower. In Table 4.2 the mean concentrations of lead and zinc in bottom (30-60 m) and surface water (0-20 m) is computed. Concentrations are corrected by subtracting the mean concentration found at the reference station in the Uummannaq region (far away from Maarmorilik) sampled in the same year. Thus the concentrations are assumed to represent the pollution contribution from the mining operation. The coefficients of variation, vZn and vPb, are computed as the standard deviation of the mean divided by the mean.

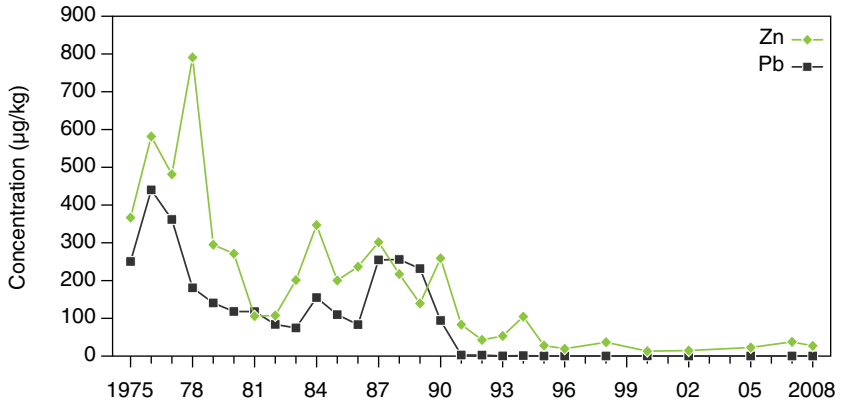
Table 4.2. Zinc and lead concentrations and coefficient of variation (vZn, vPb) in bottom and surface water of Affarlikassaa during fall, corrected for baseline concentrations (from the reference site, see text).

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
2008	21.25	0.22	0.08	0.74	0.73	4.94	-0.06	-0.3

As shown in Fig 4.6., already in 1990 (after mine closure) the lead levels in the bottom waters had declined compared to the three previous years, while zinc concentrations had increased, probably due to the waste rock dumping. The waste rock was known to release twelve times more zinc than lead (Asmund 1992). It is striking that the lead concentration has decreased drastically after mine closure in 1990. In the period 1995 to 2008 it was about 1000 times lower than in 1988-1989 and is now below 1 µg/L.

The zinc concentration in the bottom water of the Affarlikassaa fjord in 2008, however, was only about 8 times lower than in 1988-1989 and about 10 times higher than at the reference station (Fig. 4.6). Thus zinc is still released from the sediments in the Affarlikassaa fjord, and this probably will continue for decades.

Figure 4.6. Lead and zinc concentrations (µg/L) in bottom water of the Affarlikassaa fjord.

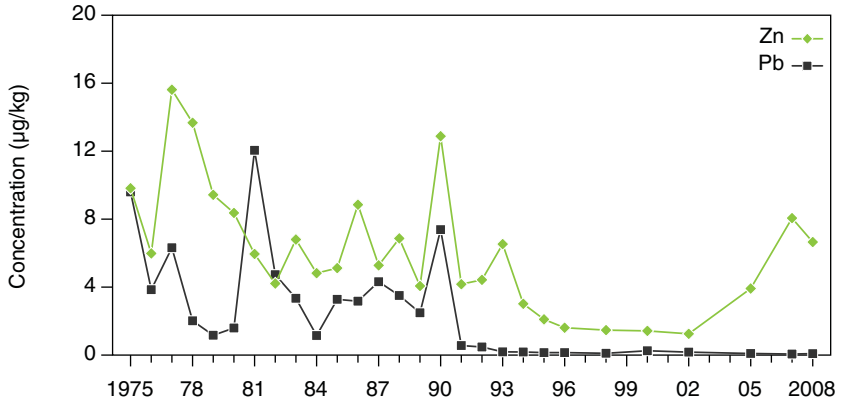


The results for the surface water are shown in Figure 4.7. While mining took place, the lead and zinc pollution in the surface water of the Affarlikassaa fjord was primarily caused by re-mixing of the heavily polluted bottom water during winter and spring.

In 1990 the movement and dumping of the Old Waste Rock Dump was a significant source of the measured zinc pollution. At that time the lead concentrations were also high probably due to the high lead content in the mine tailings resulting from mining of old oxidized ore.

After mine closure the lead concentration in the surface water deceased and remained low also in 2007 and 2008 (Fig. 4.7). The zinc concentrations, however, have only slightly declined after mine closure, and in 2007 and 2008 the concentrations were as high as in 1992. This could indicate zinc release from a land sources (likely the waste rock dumps). Another possibility might be a reduced water exchange between the Qaamarujuk and Affarlikassaa fjords in periods with high water levels in the Affarlikassaa fjord.

Figure 4.7. Lead and zinc concentrations (µg/L) in the surface water of the Affarlikassaa fjord.



In Table 4.3 the ratio between dissolved lead and zinc in the bottom and surface water of the Affarlikassaa fjord is shown. Concentrations are corrected by subtracting the mean concentration measured at the reference station in the Uummannaq region (far from Maarmorilik) in the same year. This ratio should be the same for the bottom and surface water, in case re-mixing of surface water with polluted bottom water is the only

source of contamination. This has been tested statistically (Students t-test) and the results are shown in Table 4.3.

The "p column" shows the probability that the observed difference could have appeared by chance if the to ratios actually were identical. In the cases where the $p<0.05$ and the difference therefore is significant at the 0.05 level, we have indicated a possible cause in the last column of the table.

Table 4.3. Zinc/lead relationship in bottom and surface water of the Affarlikassaa fjord, 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				Zn is from the bottom water, Pb is natural
2002	79.77	1.16				""
2005	194	1.40				""
2007	374	1.41				""
2008	279	1.85				""

In 1979 and in 1984 the Zn concentrations in the surface water were higher than could be explained by up-mixing of bottom water. We have no explanation to this. For the period 1991 to 1998 the increased lead concentrations in the surface water could not be explained by mixing with bottom water. Therefore, other sources were considered to have contributed after mine closure such as the waste rock dumps, dispersal of dust or concentrate dispersed during the mine operation (Johansen et al. 2008). In the period after 2000, including 2008, lead concentrations in the surface water of the Affarlikassaa fjord have decreased and are close to or similar to the concentrations at the reference site. It therefore gives

no meaning to calculate the Zn/Pb ratio (where Zn and Pb are the "above background concentrations")

Today, almost 20 years after mine closure in 1990, the pollution of Affarlikassaa fjord has declined drastically but it is still visible, which is likely due to release of metals from the tailings and waste rock on the seafloor and other sources on land or the intertidal zone. Gradually tailings and waste rock deposited on the bottom of the fjord will be covered by sand and silt entering the fjord with river water at the head of the fjord, thereby limiting the release of zinc and lead from this source.

4.3 Seaweed

Different seaweed species are widely used to monitor pollution with heavy metals, since they accumulate metals from seawater and therefore reflect the integrated exposure to pollution locally.

In Maarmorilik the seaweed species *Fucus vesiculosus* or *Fucus distichus* have been an essential component of the environmental monitoring. This was also the case in 2008, where seaweed was sampled at a number of stations and analyzed for lead and zinc. The results are shown in Annex 3.

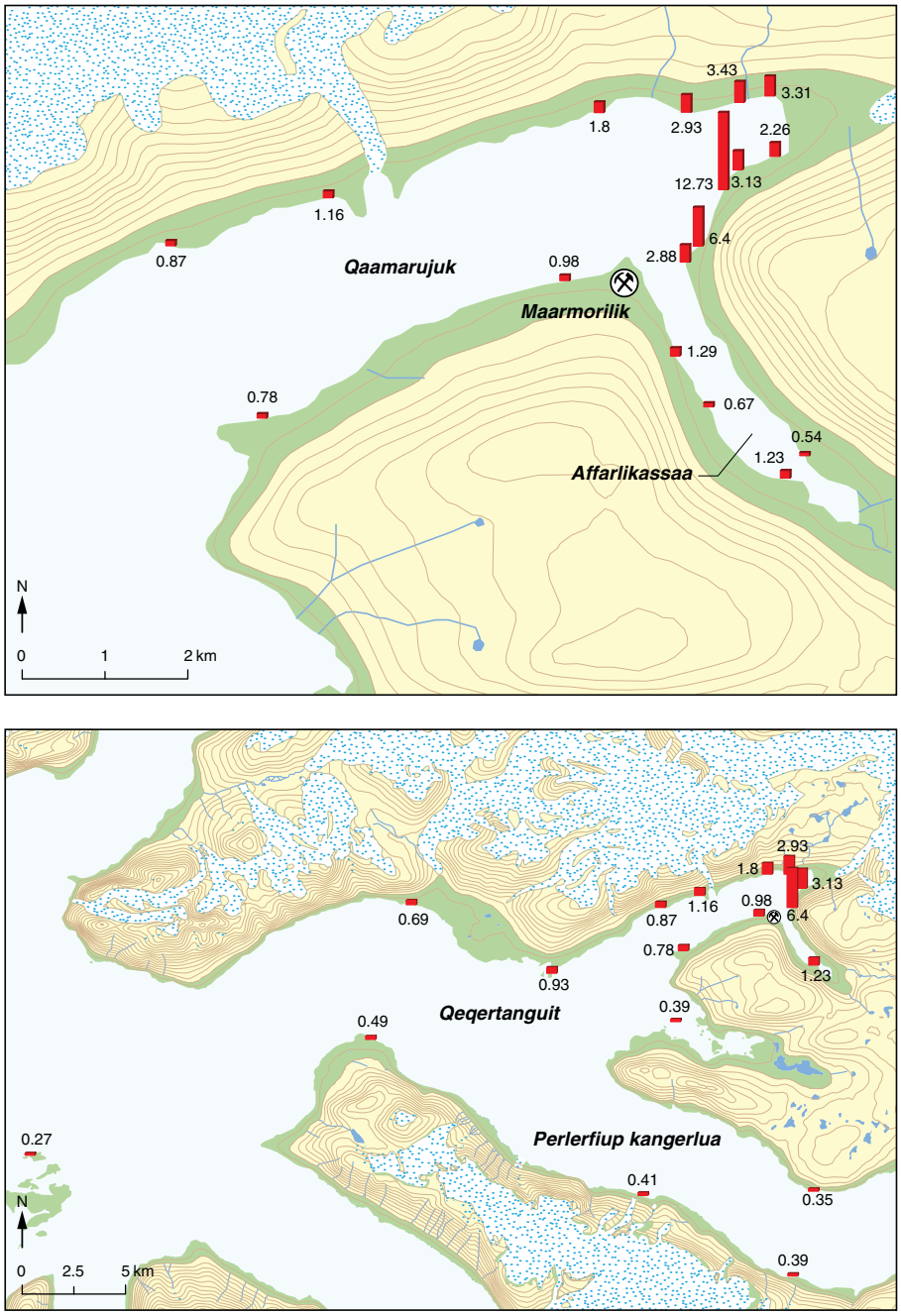
4.3.1 Spatial trends

Lead levels found are shown in Figure 4.8 and zinc levels in Figure 4.9. 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 mineralizations in the region. Locally elevated lead and zinc concentrations in seaweed have been found previously in an area with lead-zinc mineralizations at Appat in the Uummannaq region (Johansen et al. unpubl.).

In other studies performed in West Greenland it has been shown that the heavy metal concentrations were relatively low compared to other areas in Europe and North America (Riget et al. 1997a). In areas with no known local pollution sources, lead levels are in the range 0.2-0.4 µg/g and zinc levels are in the range 7-17 µg/g in brown seaweed (Riget et al. 1993, 1995).

Compared to these concentrations, lead levels in seaweed collected in 2008 were elevated, particular in the Affarlikassaa fjord and the inner Qaamarujuk (Figure 4.8). The highest levels were found just below the Black Angel Mountain. In specimens from this location, levels were elevated by a factor of about 30, indicating that this area is the main lead source (probably waste rock dumps and remains of these). In the remaining part of the Qaamarujuk and in Affarlikassaa fjords, tissue levels were elevated by a factor of 4-10. In the inner Perlerfiup fjord the lead concentration was in the same range as in seaweeds from the reference site (L) and from other parts of Greenland. However, lead levels were elevated on the northern coast of Perlerfiup kangerlua by a factor of 2-3.

Figure 4.8. Lead concentrations (µg/g dry wt) in seaweed from sampling stations close to Maarmorilik (upper graph) and further away (lower graph).



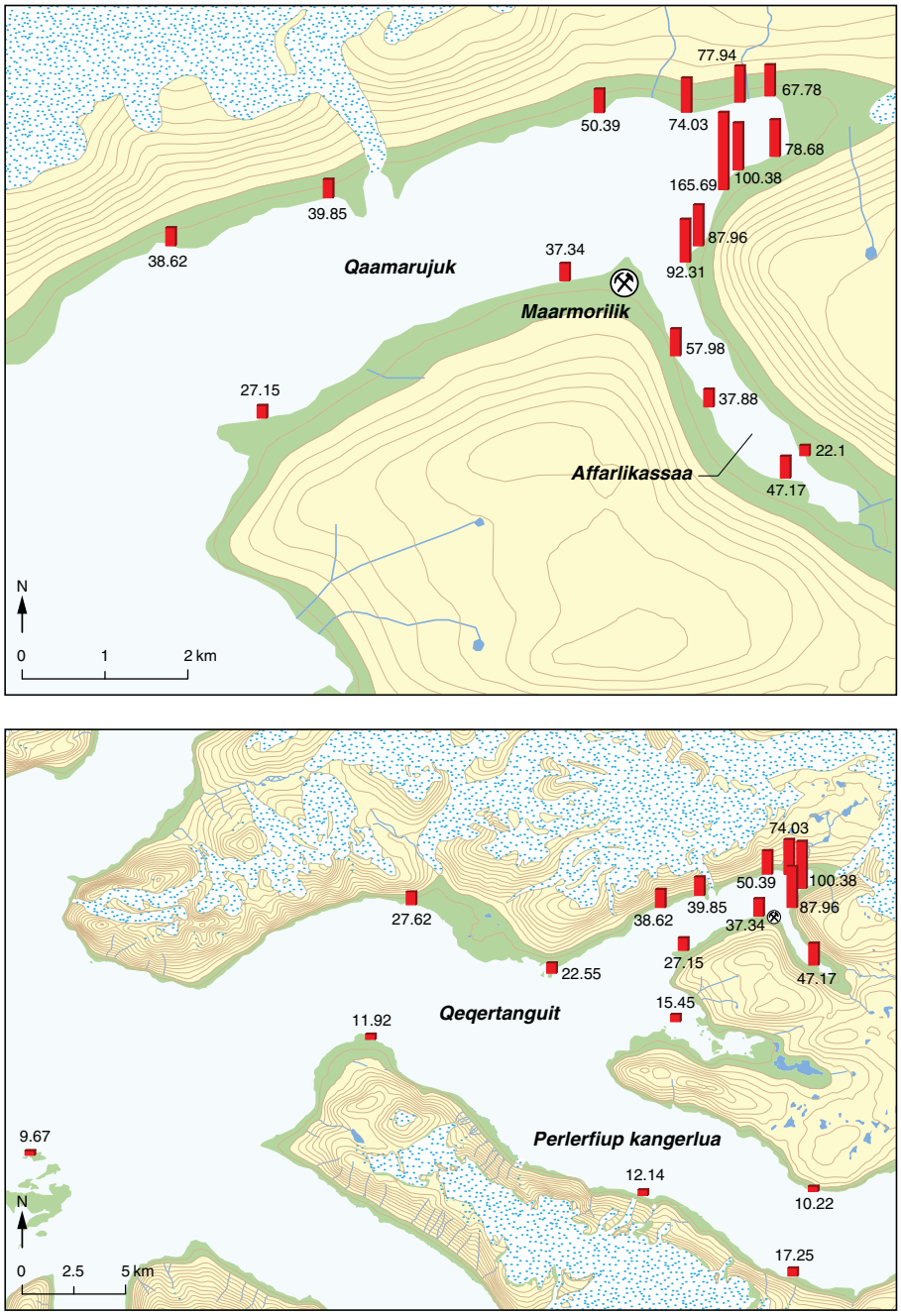


Figure 4.9. Zinc concentrations (µg/g dry wt) in seaweed from sampling stations close to Maarmorilik (upper graph) and further away (lower graph).

For zinc, a very similar pattern was found, except that zinc levels were only elevated by a factor of about 3- 10 close to Maarmorilik (Figure 4.9).

4.3.2 Temporal trends

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*), as shown in a comprehensive study carried out in Godthåbsfjord (Riget et al. 1997a).

The statistical temporal trend analyses followed the ICES (International Council for the Exploitation of the Sea) temporal trend assessment procedure (Nicholson et al. 1995). 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:

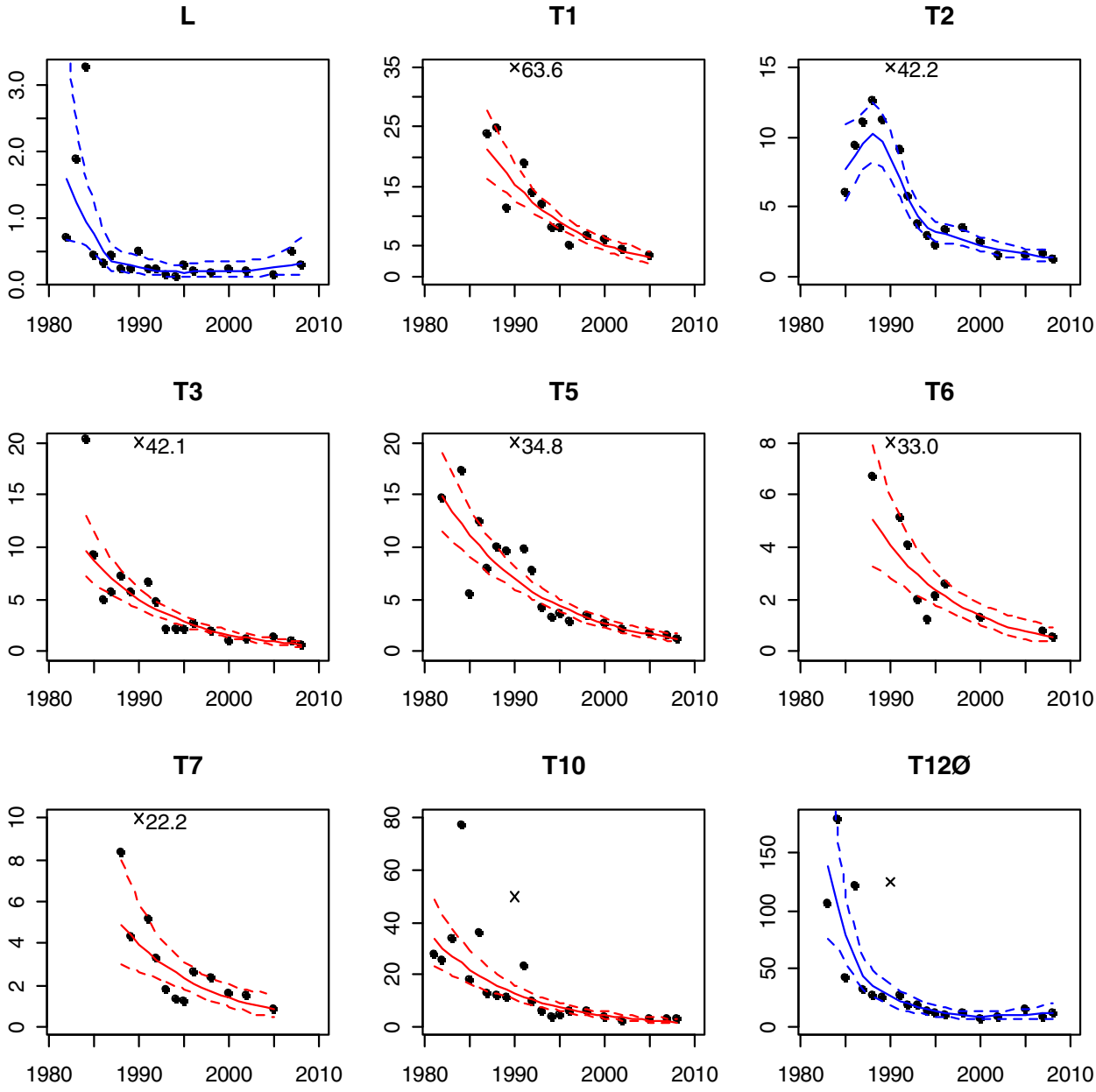
- Both log-linear and non-linear trend not significant – no temporal trend.
- Log-linear trend significant, non-linear trend not significant – log-linear trend (exponential trend)
- Both log-linear trend and non-linear trend significant – non-linear trend
- Log-linear trend not significant, non-linear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

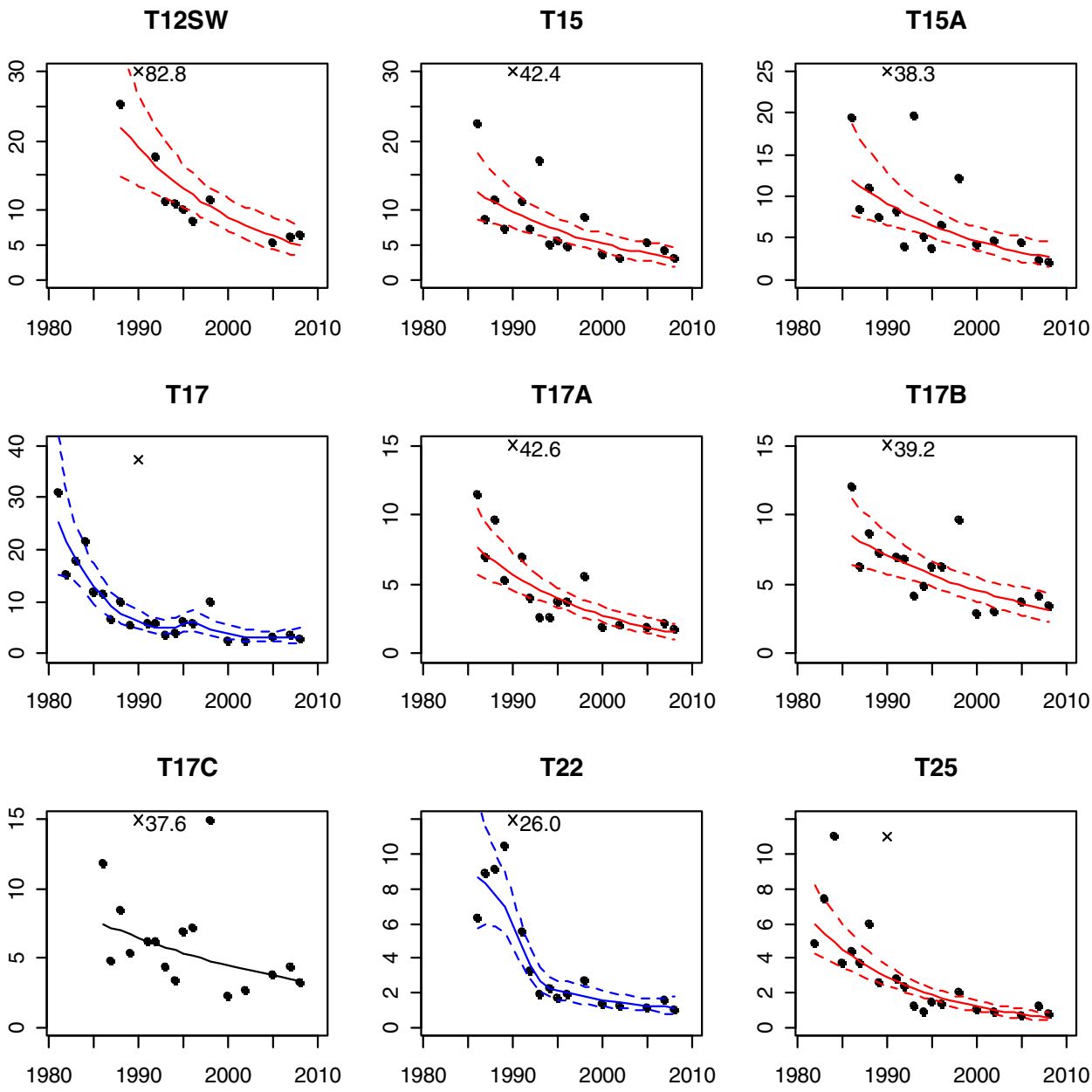
Table 4.4. Results of the temporal trend analyses of the lead concentrations in seaweed. Significance at the 5% level is shown by "sign" and non-significance by "–" for both the log-linear trend and the non-linear trend components. The overall annual change during the total period is given

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, 1985-2008	sign	sign	-9.8%	sign	sign	-8.7%
T3, 1984-2008	sign	-	-11.1%	sign	-	-9.7%
T5, 1982-2008	sign	-	-9.5%	sign	sign	-9.5%
T6, 1988-2008	sign	-	-11.1%	sign	-	-10.3%
T7, 1988-2005	sign	-	-10.5%	sign	-	-8.2%
T10, 1981-2008	sign	-	-10.8%	sign	sign	-8.3%
T12Ø, 1983-2008	sign	sign	-9.7%	sign	sign	-3.8%
T12SW, 1988-2008	sign	-	-7.4%	sign	-	-7.0%
T15, 1986-2008	sign	-	-6.4%	-	-	-6.1%
T15A, 1986-2008	sign	-	-6.8%	sign	-	-6.7%
T17, 1981-2008	sign	sign	-7.4%	-	-	-4.1%
T17A, 1986-2008	sign	-	-7.3%	sign	-	-5.5%
T17B, 1986-2008	sign	-	-4.4%	sign	-	-3.8%
T17C, 1986-2008	-	-	-3.6%	-	-	-3.4%
T22, 1986-2008	sign	sign	-9.8%	sign	-	-6.4%
T25, 1982-2008	sign	-	-8.8%	sign	-	-5.2%
T29, 1981-2008	sign	-	-9.1%	sign	-	-5.4%
T30, 1981-2008	sign	-	-9.0%	sign	-	-5.3%
T36, 1982-2008	sign	sign	-6.0%	-	-	-0.4%
T37, 1982-2008	sign	-	-7.0%	-	-	-0.2%
T38, 1982-2008	sign	sign	-5.5%	-	-	+1.7%
St. F, 1988-2008	-	sign	-1.5%	-	-	+1.2%
St. G, 1988-2008	-	sign	-1.0%	-	-	+1.8%
St. V, 1988-2008	-		-1.8%	-	-	-1.0%
St. L, 1982-2008	sign	sign	-5.4%	-	-	+3.0%

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 4.4-4.5 and Figure 4.10-4.11. The analysis has been conducted for the whole monitoring period and for the period after mine closure (1990). In the statistical analyses the 1990 data were not included. In 1990 the concentration of lead and zinc in seaweed were significantly increased in all areas monitored probably due to pollution caused by activities in relation to the dumping of waste rock into Affarlikassaa fjord, the 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 (Johansen et al. 2008).




T12SW
82.8
T15
42.4
T15A
38.3
T17
T17A
42.6
T17B
39.2
T17C
37.6
T22
26.0
T25
1980
1990
2000
2010

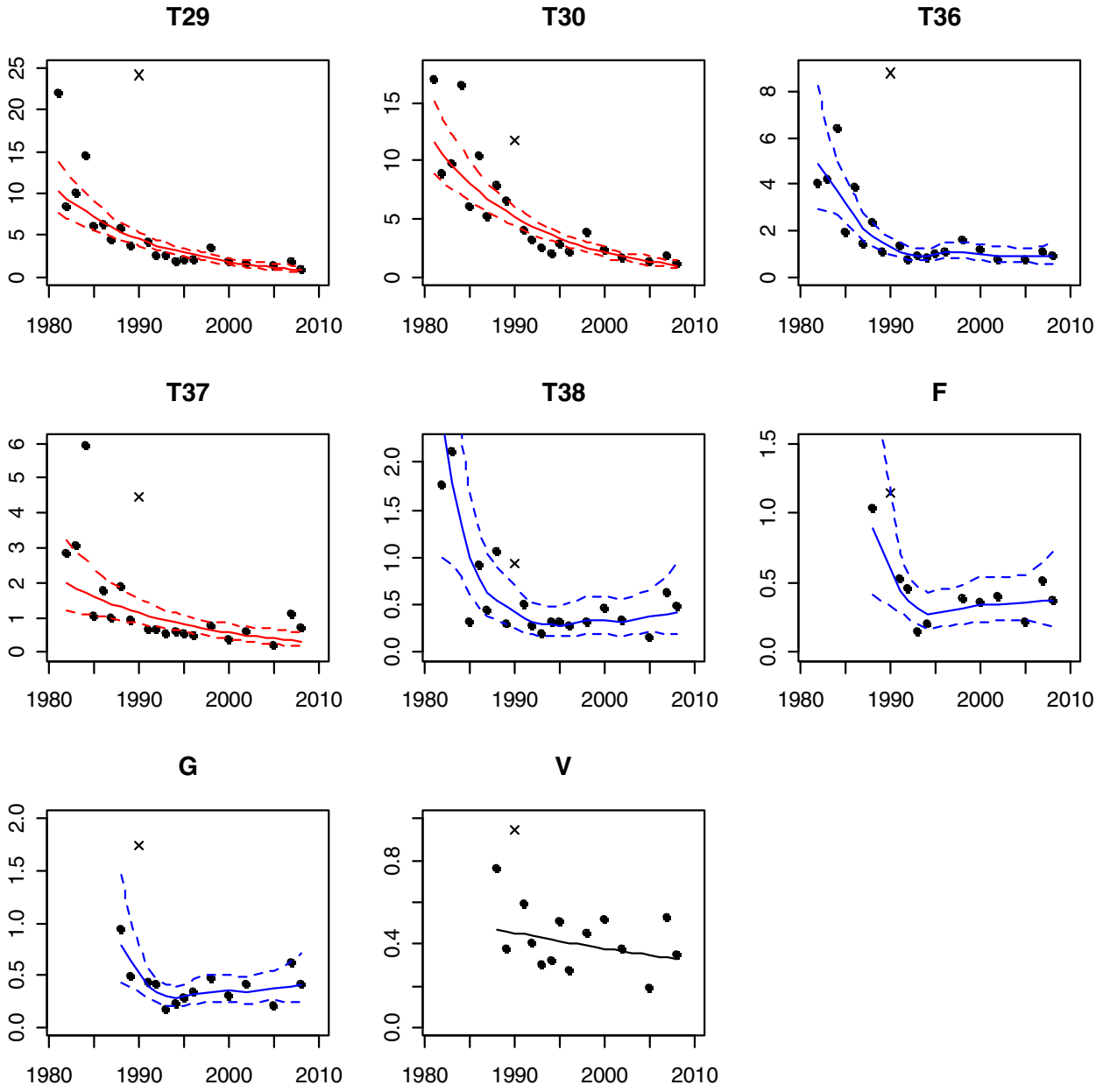


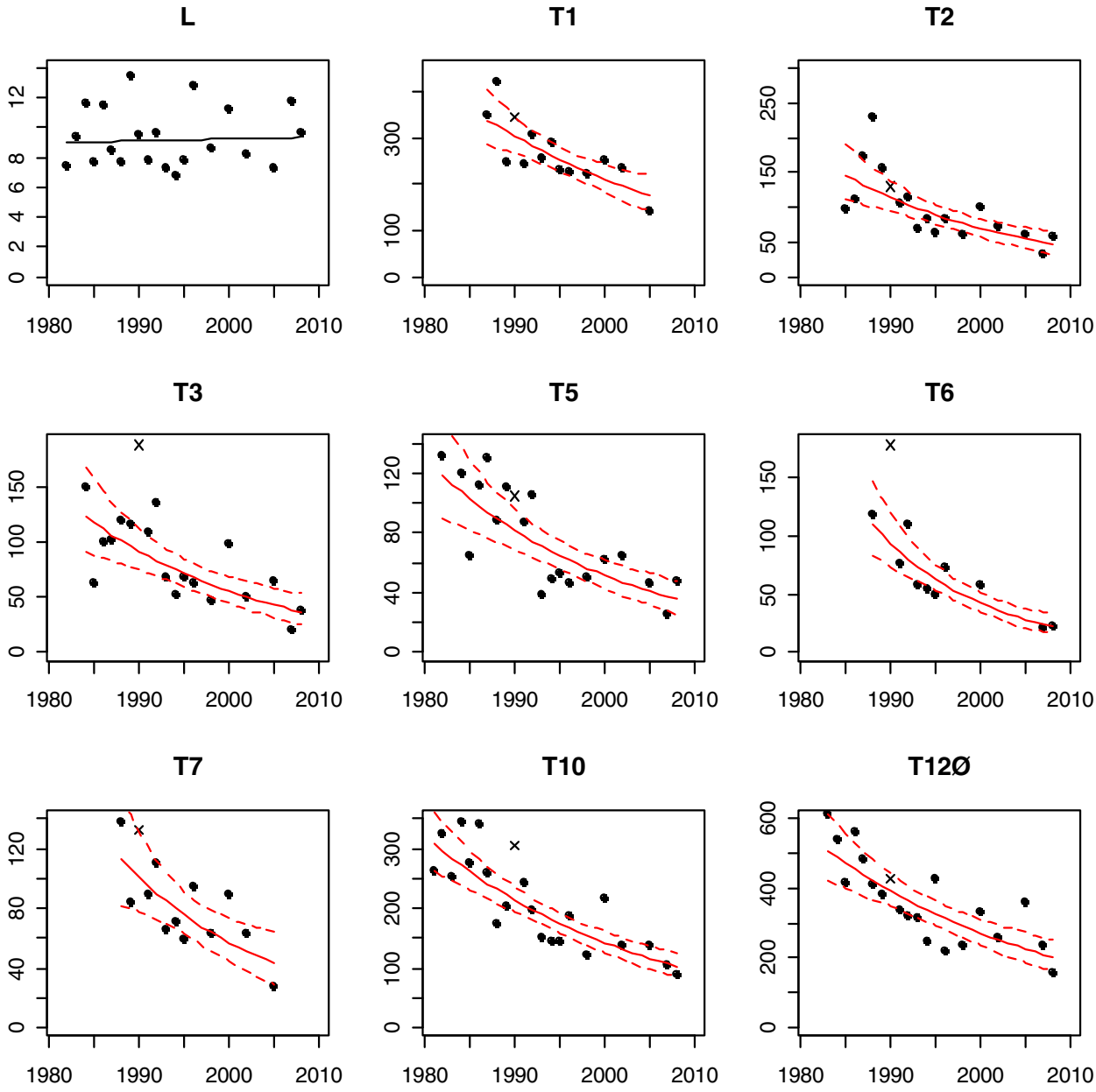
Figure 4.10. Temporal trend of the lead concentrations (mg/kg dry wt) in seaweed. Points denote annual geometric mean concentrations. A solid line together with 95% confidence broken lines is given when a significant trend was found in the temporal trend analysis. A solid line alone is given when no significant trend was found. Red lines indicate log-linear trends and blue lines non-linear trend. L, T1, T2,….T30, T36,… are station numbers, see Figure 2.1

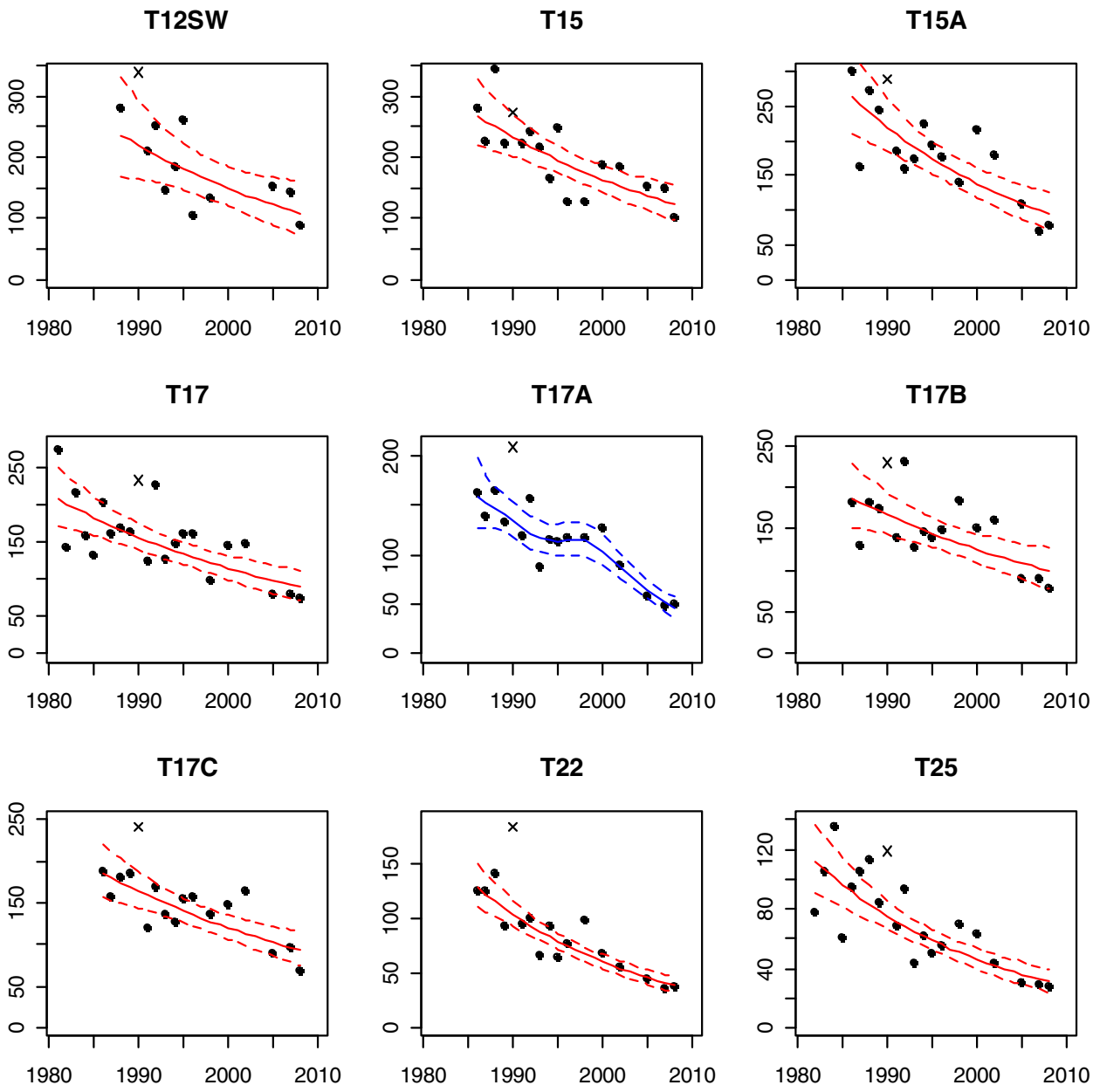
Over the entire monitoring period lead concentrations in seaweed have decreased at all stations. This decrease, ranging from 1.6 to 11.3% per year, is significant ($p < 0.05$) for nearly all stations and can be described as a log-linear trend, meaning an exponential decrease. After mine closure in 1990 lead concentrations have also decreased, but this decrease is significant at fewer stations and the annual change is lower 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.

A similar time trend than for lead was found for zinc. Zinc concentrations in seaweed have decreased at most of the stations but they are still higher than at station L (furthest away from Maarmorilik). Station L can be seen as reference since zinc concentrations are similar to the levels found at reference sites unaffected by known local sources. Since 1990 the concentrations found at station L ranged between 6-14 µg/g dry wt).

Table 4.5. 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, 1982-2008	-	-	0.1%	-	-	+1.1%
T1, 1987-2005	sign	-	-3.7%	sign	-	-3.3%
T2, 1985-2008	sign	-	-4.9%	sign	-	-4.0%
T3, 1984-2008	sign	-	-5.1%	sign	-	-6.0%
T5, 1982-2008	sign	-	-4.6%	-	-	-3.3%
T6, 1988-2008	sign	-	-8.0%	sign	-	-7.8%
T7, 1988-2005	sign	-	-5.7%	sign	-	-5.7%
T10, 1981-2008	sign	-	-4.1%	sign	-	-3.6%
T12Ø, 1983-2008	sign	-	-3.7%	-	-	-2.2%
T12SW, 1988-2008	sign	-	-3.9%	-	-	-3.4%
T15, 1986-2008	sign	-	-3.6%	sign	-	-3.2%
T15A, 1986-2008	sign	-	-4.7%	sign	sign	-5.0%
T17, 1981-2008	sign	-	-3.1%	sign	-	-4.4%
T17A, 1986-2008	sign	sign	-4.9%	sign	sign	-5.5%
T17B, 1986-2008	sign	-	-2.8%	sign	-	-3.9%
T17C, 1986-2008	sign	-	-3.1%	sign	sign	-3.2%
T22, 1986-2008	sign	-	-5.4%	sign	-	-5.4%
T25, 1982-2008	sign	-	-4.9%	sign	-	-5.4%
T29, 1981-2008	sign	-	-4.4%	sign	sign	-4.6%
T30, 1981-2008	sign	-	-4.5%	sign	sign	-4.7%
T36, 1982-2008	sign	-	-3.4%	sign	sign	-3.4%
T37, 1982-2008	sign	-	-2.2%	-	-	-0.1%
T38, 1982-2008	sign	-	-1.8%	-	sign	-1.3%
St. F, 1988-2008	-	-	-2.1%	-	-	-1.5%
St. G, 1988-2008	sign	-	-2.5%	-	-	-2.1%
St. V, 1988-2008	sign	-	-3.4%	sign	-	-3.5%


L
T1
T2
T3
T5
T6
T7
T10
T12Ø
1980
1990
2000
2010


T12SW
T15
T15A
T17
T17A
T17B
T17C
T22
T25
1980
1990
2000
2010

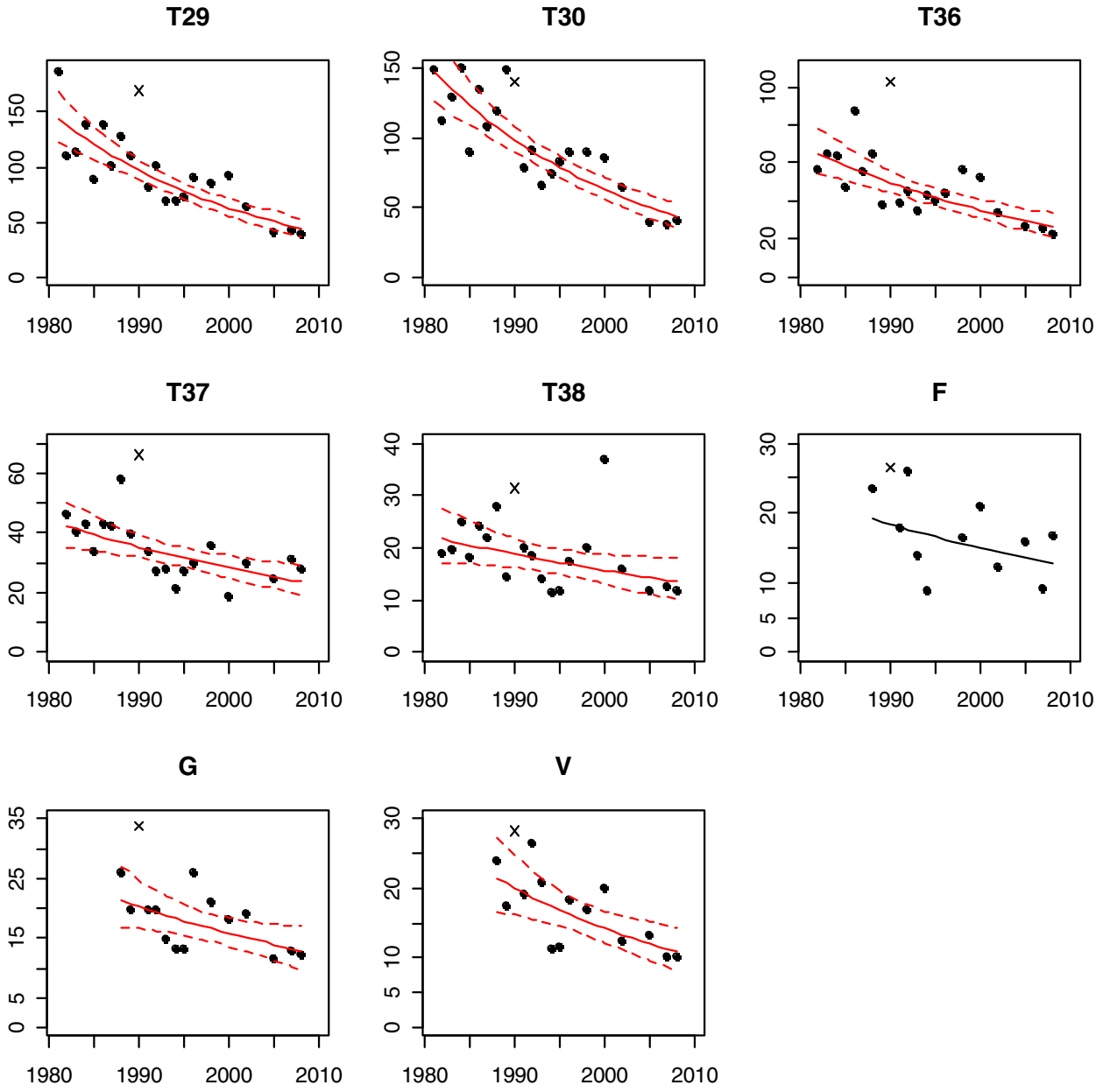


Figure 4.11. Temporal trend of the zinc concentrations (mg/kg dry wt) in seaweed. Points denote annual geometric mean concentrations. A solid line together with 95% confidence broken lines is given when significant trend was found in the temporal trend analysis. A solid line alone is given when no significant trend was found. Red lines indicate log-linear trends and blue lines non-linear trend. L, T1, T2,….T30, T36,… are station numbers, see Figure 2.1

In the following the overall temporal trend for the lead and zinc in seaweed is illustrated in selecting a set of stations representing different sub areas in terms of distance to the mine and concentration levels:

At the mine: T 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.

The mean concentrations have been computed and are presented in Figures 4.12 and 4.13.

Figure 4.12. Lead concentrations (µg/g dry wt) in seaweed over time relative to the distances from the mine.

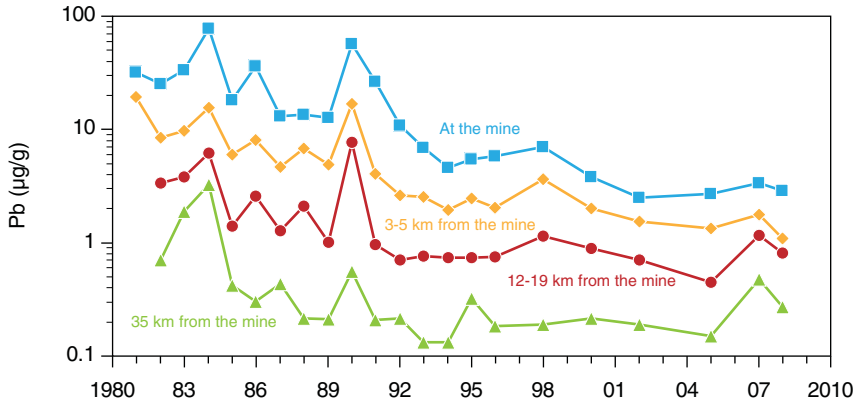
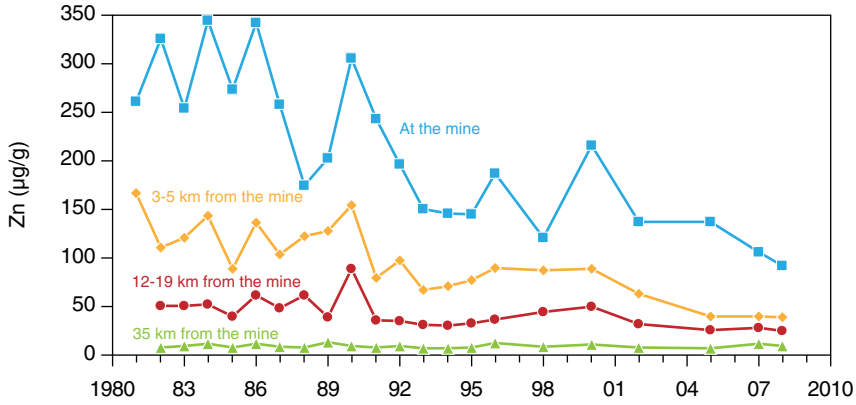


Figure 4.13. Zinc concentrations (µg/g dry wt) in seaweed over time relative to the distances from the mine.



It may be concluded that the lead and zinc concentrations in seaweed have significantly decreased over the entire monitoring period (since 1981) and in most cases exponential. The lead concentrations have decreased faster than the zinc concentrations. However, in 2008 lead and zinc concentrations are still elevated in seaweed from Affarlikassaa, Qaamarujuk and the northern coast of Perlerfiup kangerlua.

4.4 Blue mussel

Like seaweeds, blue mussels (*Mytilus edulis*) have widely been used to monitor heavy metal pollution. Also in Maarmorilik they have been an important tool to monitor the impact of the mining operation both during mining and after closure. The monitoring programme has consisted of sampling both resident mussels and mussels which were transplanted from a site unaffected by the mining to the fjords at Maarmorilik.

Sampling of resident mussels, i.e. mussels that have lived all their life in the area where they were sampled, is mainly conducted to evaluate the spatial extent of the area affected by pollution (e.g. lead) and to advice on the risk for human health of collecting and eating contaminated mussels.

Transplanting mussels and collect them a year later allows assessing the temporal trend of the lead contamination. This method was introduced in Maarmorilik, after it was observed that contaminated mussels did not

release lead at the same rate as the lead pollution in the surrounding water decreased. In previous studies it was observed that contaminated mussels after living 2-3 years in an uncontaminated area still contained about half of the lead content they had before. After that period they did not release lead at all (Riget et al. 1997b). By transplanting mussels from a reference site unaffected by the mine to the fjords at Maarmorilik and analyzing them one year later this provides a measure of the exposure for the period of one year.

In 2008 two size groups of blue mussels were collected at most stations and the lead and zinc concentrations were measured. The results are shown in Annex 4.

4.4.1 Spatial trends

The lead concentrations measured in resident blue mussels at the different stations are shown in Figure 4.14 and Figure 4.15. In blue mussels from the Uummannaq region, with no known local sources, lead and zinc concentrations (µg/g dry weight) range between:

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

Compared to these levels the lead concentration in blue mussels is elevated (in all analysed size groups) in all of the study area (Figure 4.14 and 4.15), whereas zinc levels are only elevated close to Maarmorilik and in the inner part of Qaamarujuk (Annex 4). In the most affected area below the Black Angel Mountain and at Maarmorilik, 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 2-20. The lead concentration differs between the two size groups with higher levels in the larger mussels (6-7 cm shell length). Shell length in an indicator for age which means the large mussel are older and thus been exposed over a longer period than the smaller ones. Moreover, lead is only released at a low rate from the mussels, if the exposure ceases (Riget et al. 1997b).

Figure 4.14. Lead concentrations (µg/g dry wt) in small blue mussels (5-6 cm shell length) from sampling stations close to Maarmorilik (upper graph) and further away (lower graph).

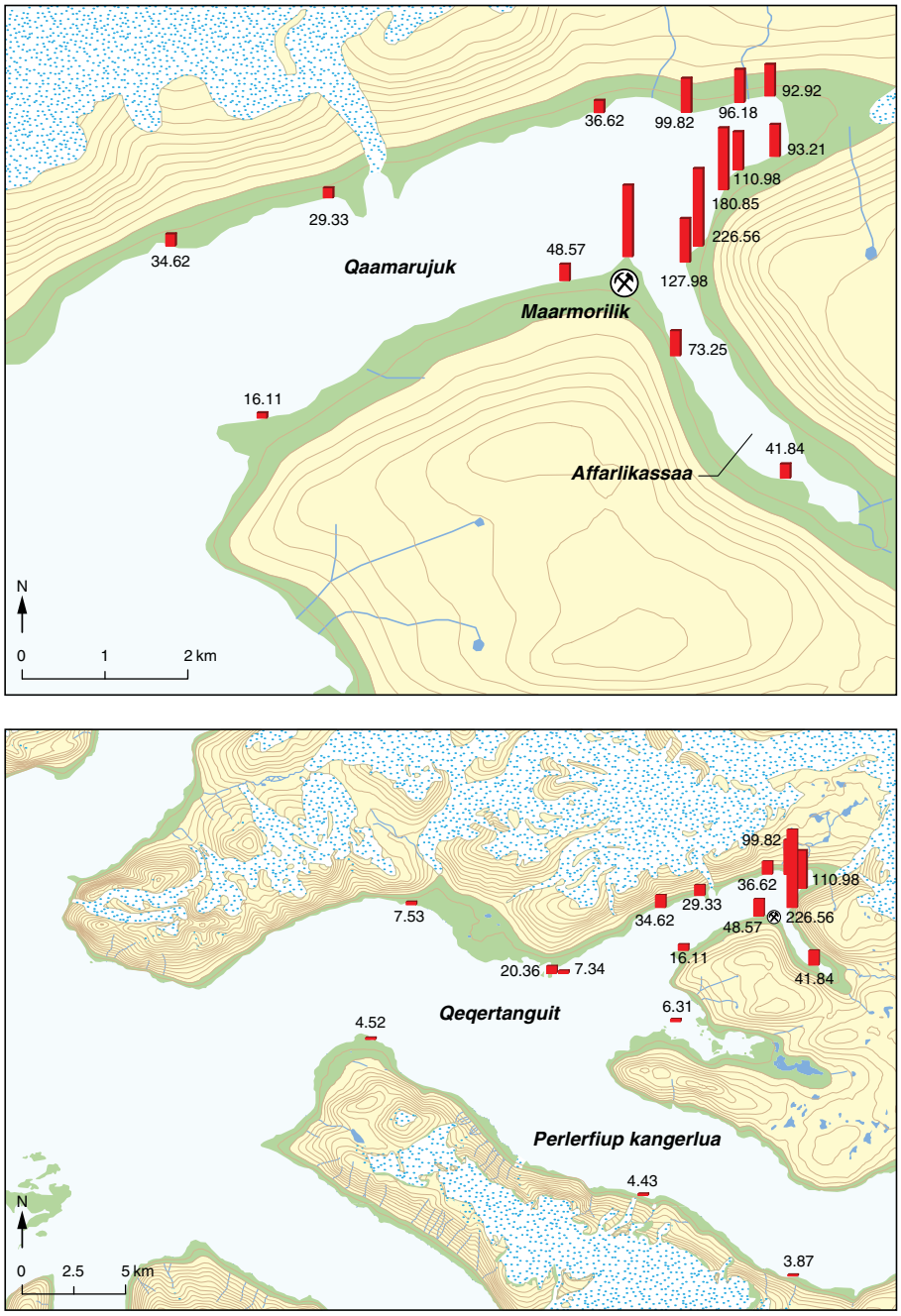
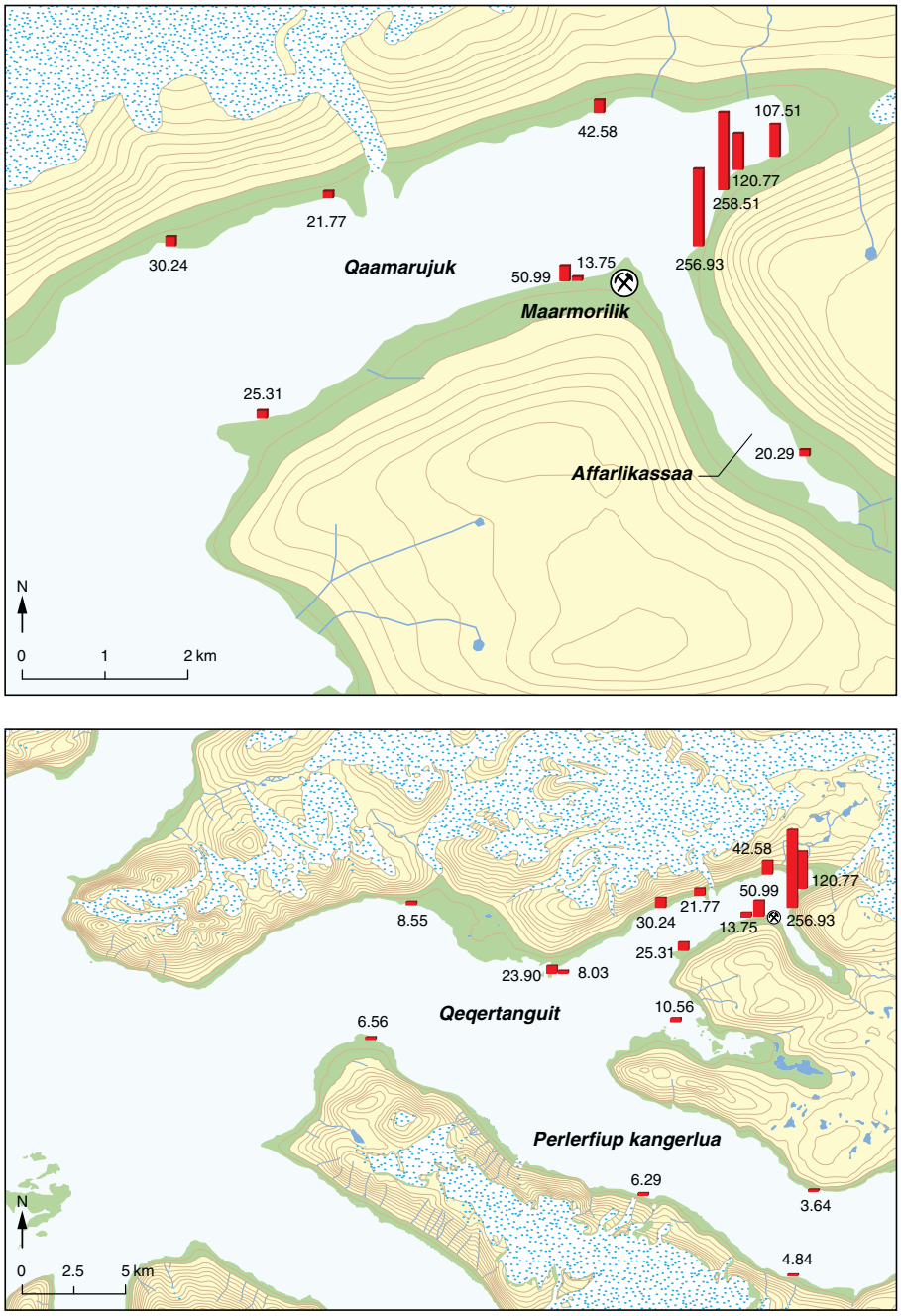


Figure 4.15. Lead concentration (µg/g dry wt) in large blue mussels (shell length 6-7 cm) from sampling stations close to Maarmorilik (upper graph) and further away (lower graph). Column in yellow indicate lead content in transplanted mussels.



4.4.2 Temporal trend – resident mussels

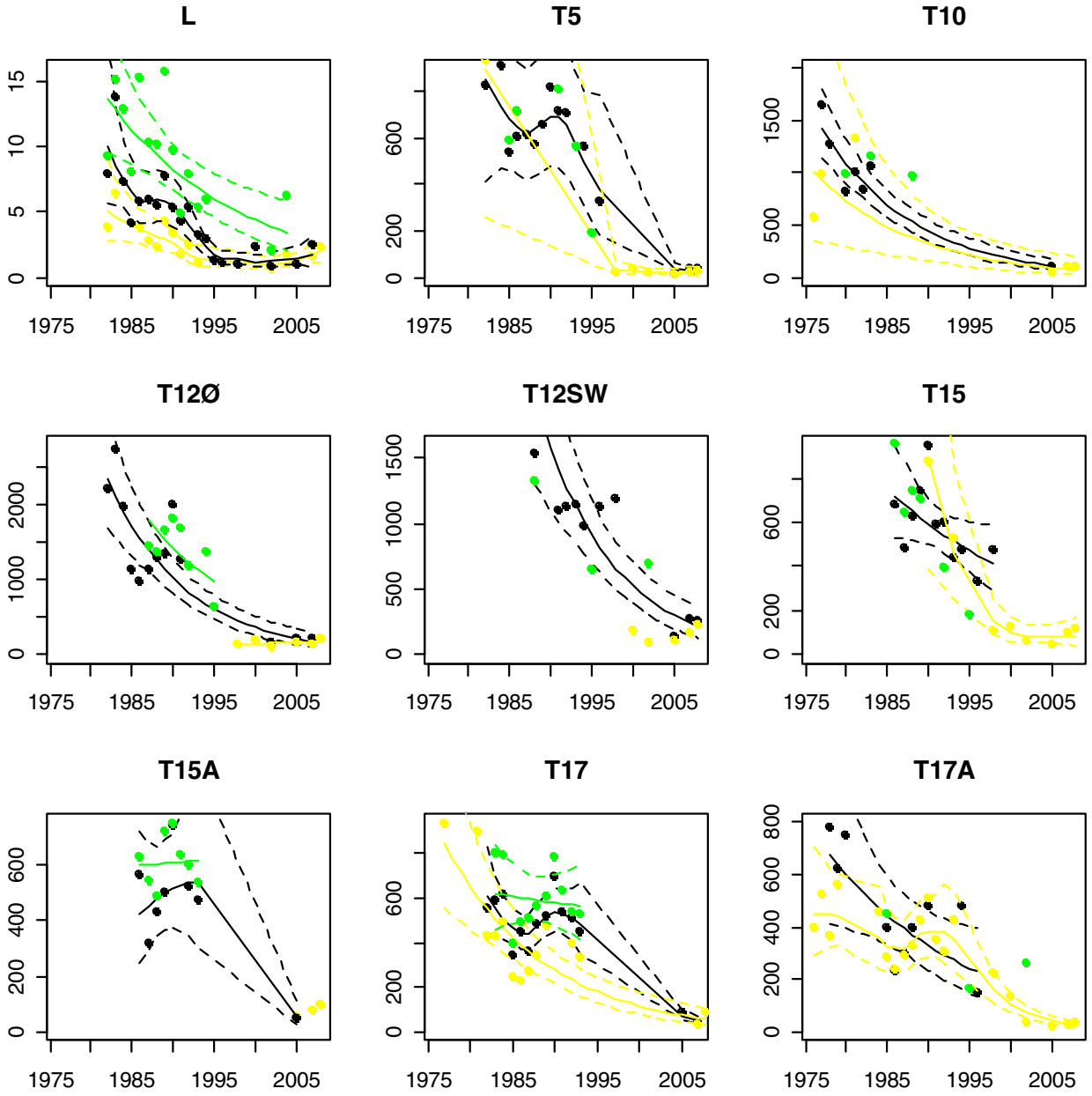
A time trend analysis was conducted for the lead and zinc concentrations in resident blue mussels using the same method as described for seaweed (section 4.3.2). The results are shown in Table 4.6 and 4.7 and Figures 4.16 and 4.17. Lead concentrations in blue mussels have decreased in the whole monitoring 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.

Table 4.6. 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 (≥ 6 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, 1982-2008	sign	sign	-4.6%	sign	sign	-8.0%
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, < 1g, 1982-2008	sign	-	-14.6%	-	-	-2.5%
T5, 1-2g, 1982-2007	sign	sign	-14.3%	sign	-	-21.1%
T10, <1 g, 1976-2008	sign	-	-8.2%			
T10, 1-2g, 1977-2005	sign	-	-9.0%			
T12Ø, <1g , 1998-2008	-	-	2.4%			
T12Ø, 1-2g, 1983-2007	sign	-	-10.3%			
T12Ø, >2g, 1987-1995	-	-	-7.7%			
T12SW, 1-2g, 1988-2008	sign	-	-11.0%	sign	-	-11.20%
T15, <1g, 1986-2008	sign	sign	-13.1%	sign	-	-10.1%
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, 1977-2008	sign	-	-8.6%			
T17, 1-2g, 1982-2007	sign	sign	-9.2%			
T17, >2g, 1983-1993	-	-	-1.0%			
T17A, <1g, 1976-2008	sign	sign	-8.7%	sign	-	-16.5%
T17A, 1-2g, 1978-1996	sign	-	-6.0%			
T17B, <1g, 1986-2008	sign	sign	-12.8%	sign	-	-15..6%
T17B, 1-2g, 1986-2007	sign	sign	-12.3%	sign	-	-16.4%
T17C, 1-2g, 1986-2005	sign	sign	-12.3%			
T22, <1g, 1998-2008				-	-	-0.6%
T22, 1-2g, 1986-2005	sign	sign	-16.1%	sign	-	-23.3%
T25, <1g, 1982-2008	sign	-	-12.9%			
T25, 1-2g, 1982-2002	sign	sign	-8.5%	sign	sign	-22.5%
T29, <1g, 1977-2008	sign	sign	-9.4%	sign	-	+2.0%
T29, 1-2g, 1976-2002	sign	-	-1.5%	-	-	-3.6%
T30, <1g, 1976-2008	sign	sign	-10.0%			
T30, 1-2g, 1976-2002	sign	sign	-4.4%	sign	-	-12.6%
T36, <1g, 1978-2008	sign	sign	-10.1%	sign	-	-8.8%
T36, 1-2g, 1978-2002	sign	sign	-6.7%	sign	-	-20.6%
T36, >2g, 1978-2002	sign	-	-5.3%			
T37, <1g, 1981-2008	sign	sign	-13.2%			
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%			

After mine closure in 1990 the lead concentration in blue mussels has decreased at a faster rate than over the whole monitoring period (Table 4.6). 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%.



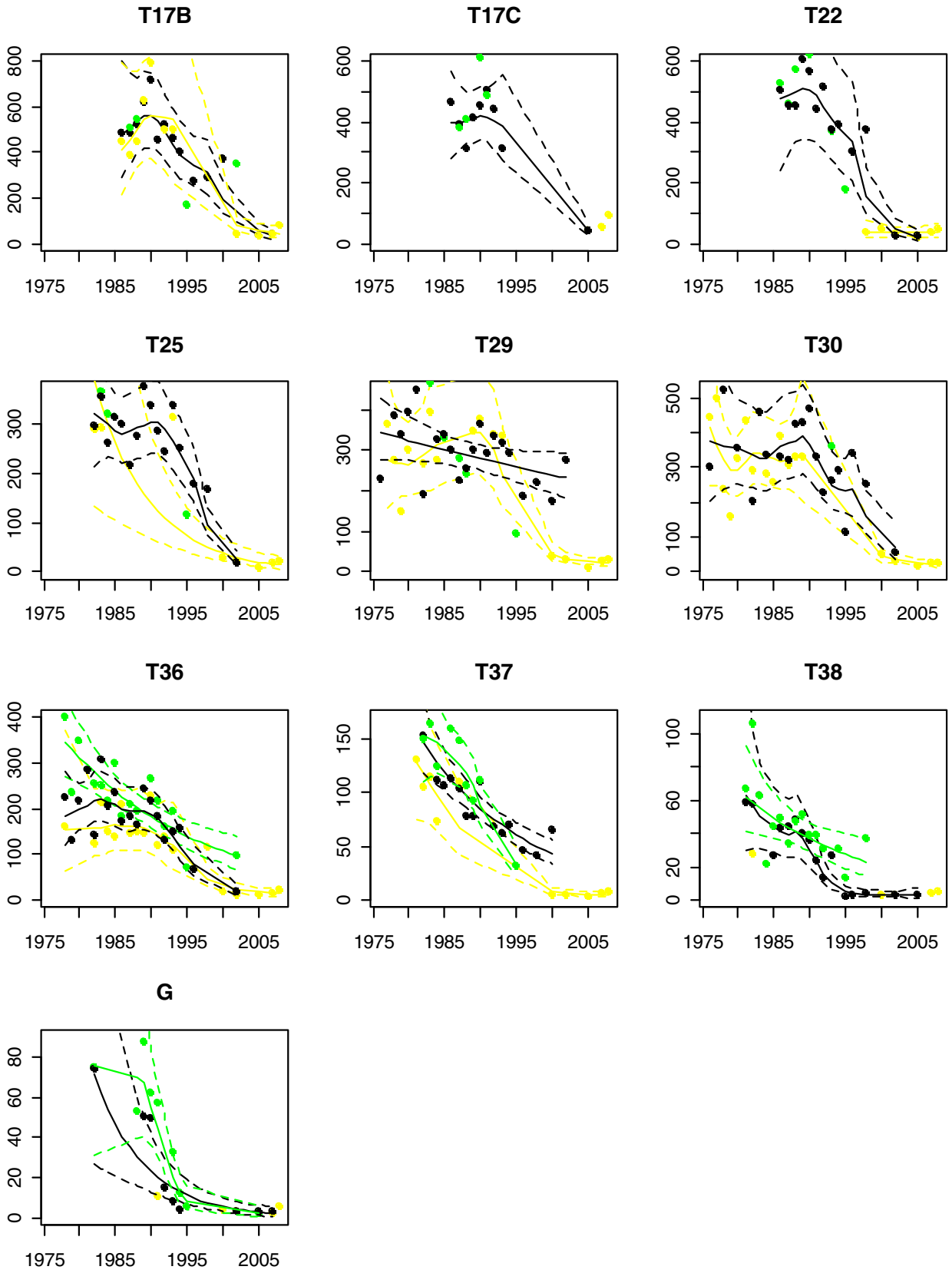


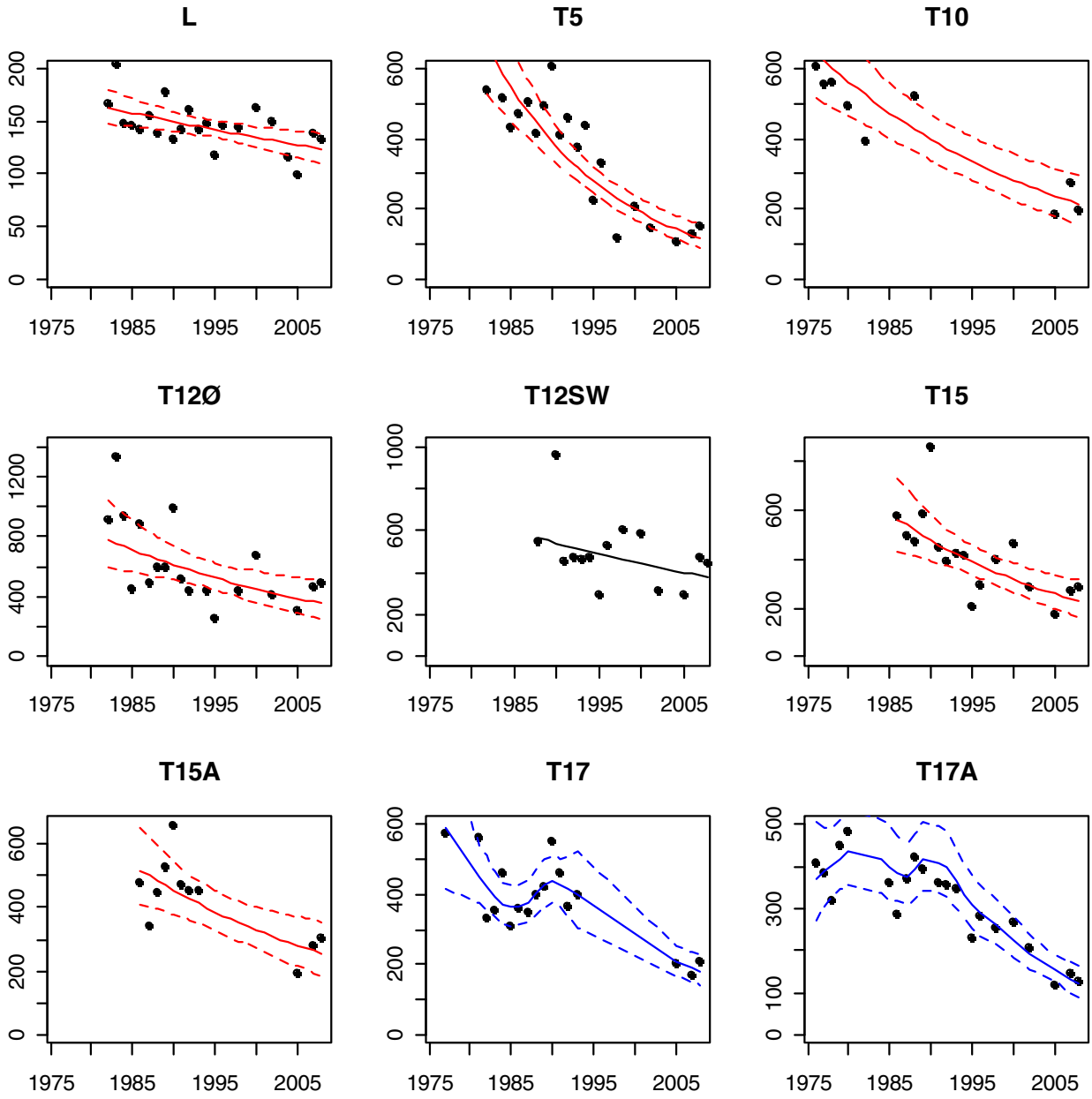
Figure 4.16. Temporal trend of Pb concentrations in blue mussels. Yellow colours denote results of size group < 1g, black colours denote results of size group 1-2 g and green colour denotes results of size group > 2g. Points and solid trend line together with 95% confidence broken lines are given when significant trend was found in the temporal trend analysis. Points and solid line are given when no significant trend was found. Only points are given when no temporal trend analysis has been performed.

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 (Table 4.7). 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. 1997b). The second explanation is that the blue mussels that were polluted during the period of mining have gradually disappeared (being eaten or died of natural causes), new generations has emerged which will be exposed to lower concentrations. Blue mussels aged 15 years or more were rarely found in a study of growth in Disko Bay (Theisen 1973).

Table 4.7. 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 (≥6 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, 1982-2008	sign	-	-1.1%	-	-	-1.1%
T5, 1982-2008	sign	-	-6.7%	sign	-	-7.9%
T10, 1976-2008	sign	-	-3.4%			
T12Ø, 1982-2008	sign	-	-3.0%	-	-	+0.2%
T12SW, 1988-2008	-	-	-2.0%	-	-	-0.8%
T15, 1986-2008	sign	-	-4.1%	-	-	-2.9%
T15A, 1986-2008	sign	-	-3.2%	sign	-	-3.8%
T17, 1977-2008	sign	sign	-3.2%			
T17A, 1976-2008	sign	sign	-3.5%	sign	-	-6.9%
T17B, 1986-2008	sign	-	-5.2%	sign	-	-5.6%
T17C, 1986-2008	sign	sign	-2.7%	sign	-	-3.9%
T22, 1986-2008	sign	-	-6.7%	sign	-	-6.9%
T25, 1982-2008	sign	sign	-4.0%	sign	-	-6.3%
T29, 1977-2008	sign	sign	-2.9%	sign	-	-5.5%
T30, 1976-2008	sign	sign	-3.0%	sign	-	-6.2%
T36, 1978-2008	sign	-	-3.6%	sign	-	-5.2%
T37, 1981-2008	sign	-	-3.7%	sign	-	-5.0%
T38, 1981-2008	sign	-	-2.5%	-	-	-1.0%
St.G, 1982-2008	sign	sign	-3.5%	-	-	-0.9%


L
T5
T10
T12Ø
T12SW
T15
T15A
T17
T17A
1975
1985
1995
2005

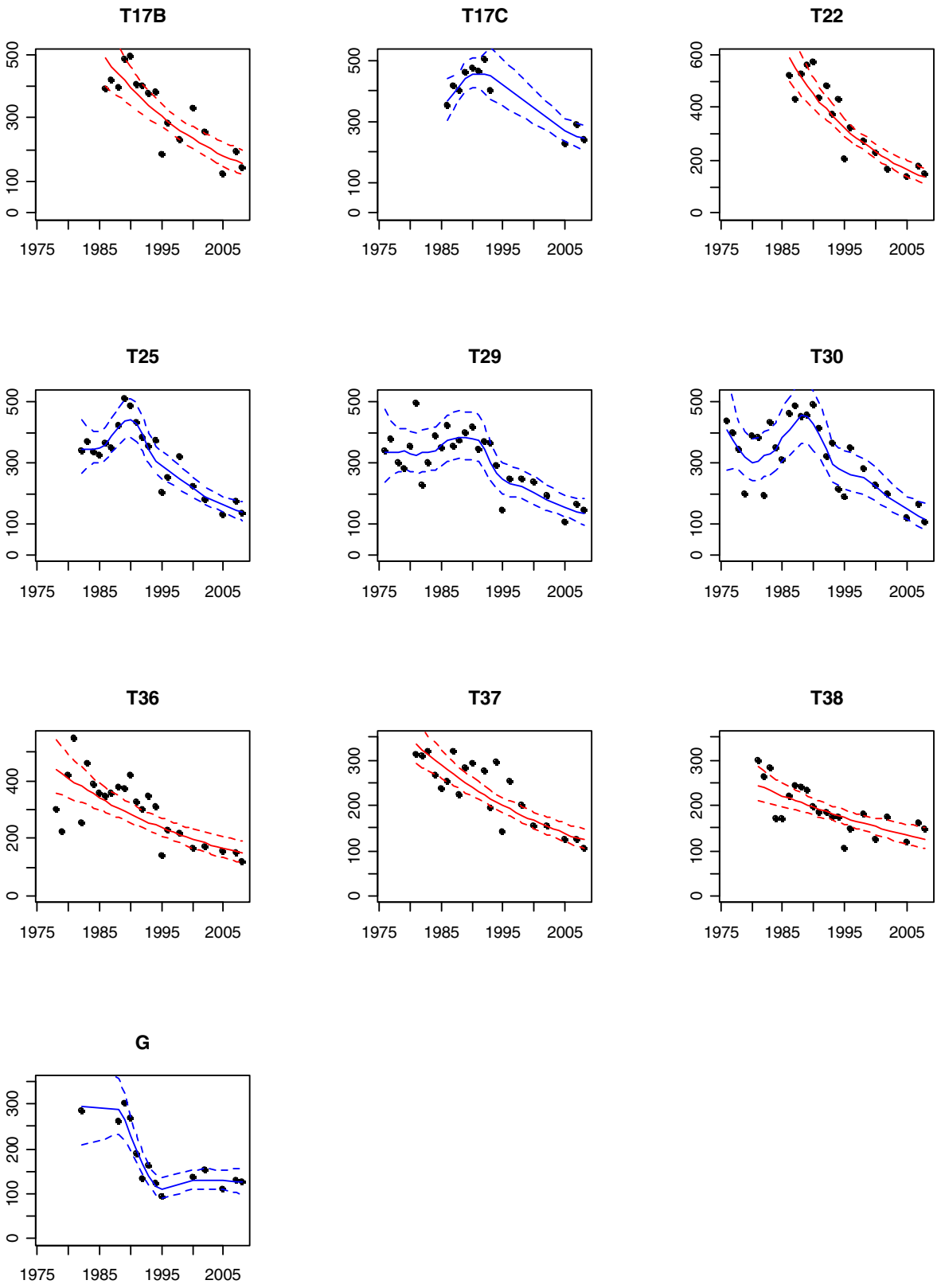


Figure 4.17. Temporal trend of zinc concentrations in blue mussels. Red colours denote results of size group < 1g, black colours denote results of size group 1-2 g and green colour denotes results of size group > 2g. Points and solid trend line together with 95% confidence broken lines are given when 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.

4.4.3 Transplantation of blue mussels

In 2007 blue mussels were transplanted to 11 stations in the fjords at Maarmorilik. Unfortunately, in 2008, mussels from only two stations were found (T22 and T36). Therefore only few conclusions can be drawn.

Similar transplantation experiments have been performed regularly since 1991. In some cases the bodyweight was lower in the transplanted mussels after one year, resulting in increased lead concentrations in the tissues. In order to compensate this effect, the lead and zinc content has been computed and normalized to a standard size, i.e. 6 cm shell length based on available data for length/weight relationship for each location. The results are shown in Table 4.8 (lead) and 4.9 (zinc).

After staying one year at the new locations, in 2008 the lead content in the transplanted mussels was clearly lower than in the resident mussels but clearly higher than in mussels from Station L, which is their original location (Fig. 4.14).

4.4.4 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 wt) 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 wt 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 estimate the area of the coastline where the "maximum allowed level" is exceeded, we have extrapolated the values found at station T36 and T37 on the northern and T25 and T33 on the southern coast of Perlerfiup kangerlua. The result is shown in Figure 4.18; for the coastline marked in red it is recommended not to collect and eat blue mussels. This area is similar to that found in 2005 (Johansen et al. 2006) and 2007 (Johansen et al. 2008), but much smaller than it used to be. Until 2005 it also included all of Perlerfiup kangerlua (Johansen et al. 2006).

Tabel 4.8. Mean lead content (µg Pb) in resident and transplanted mussels at different monitoring locations around Maarmorilik. The lead content has been normalized to a mussel with 6 cm shell length.

Lead	**Resident**							**Transplanted**											
Trans year								**1994**	**1994**	**1994**	**1995**	**1995**	**1996**	**1996**	**1996**	**1998**	**1998**	**2000**	**2007**
Collecting year	**1994**	**1995**	**1996**	**1997**	**1998**	**2002**	**2007**	**1995**	**1996**	**1997**	**1996**	**1997**	**1997**	**1998**	**2002**	**1999**	**2002**	**2002**	**2008**
L	5,27	1,69	1,11		1,11	1,15	1,80											1,58	
Schade		0,55	1,03	0,66	0,86														
T5								19,7	43,1		25,9		20,5			11,7	15,5		
T12Ø								103					134			95,3			
T12SV								116	365	273	164	178	89,4			118			
T17A								18,4	42,2	42,0	17,6	34,1	19,5			15,4		12,6	
T17B								19,0	48,3		19,9	34,7	21,6	42,2		22,2		21,9	
T22								18,5	37,8		20,5	29,5	13,5		32,0	11,0			9,82
T25								11,0	18,1	23,5	11,1	11,5	6,99			6,10		8,51	
T30								9,35	21,2		12,1	10,0	5,78			8,05			
T36								9,75			5,25	7,18	4,77			7,20		5,60	4,36
G								4,02	5,13	6,35	1,53	2,86	2,24	5,18		2,77		3,35	
V								3,74	3,97	4,25	2,03	2,53	1,74			2,79			

Tabel 4.9. Mean zinc content (µg Zn) in resident and transplanted mussels at different monitoring locations around Maarmorilik. Zinc content has been normalized to a mussel with 6 cm shell length

Zinc	**Resident**							**Transplanted**											
Trans year								**1994**	**1994**	**1994**	**1995**	**1995**	**1996**	**1996**	**1996**	**1998**	**1998**	**2000**	**2007**
Collecting year	**1994**	**1995**	**1996**	**1997**	**1998**	**2002**	**2007**	**1995**	**1996**	**1997**	**1996**	**1997**	**1997**	**1998**	**2002**	**1999**	**2002**	**2002**	**2008**
L	178	150	148		157	138	125											188	
Schade			135	108	121														
T5								165	142		166		178			157	170		
T12Ø								293					426			313			
T12SV								294	445	349	347	353	289			270			
T17A								170	172	191	146	168	172			151		163	
T17B								140	199		138	171	174	235		137		240	
T22								206	188		140	185	169		191	144			119
T25								179	153	141	168	163	136			112		153	
T30								122	126		147	92	101			143			
T36								183			183	136	143			148		151	111
G								170	221	131	112	126	141	158		129		151	
V								153	137	120	112	119	123			177			

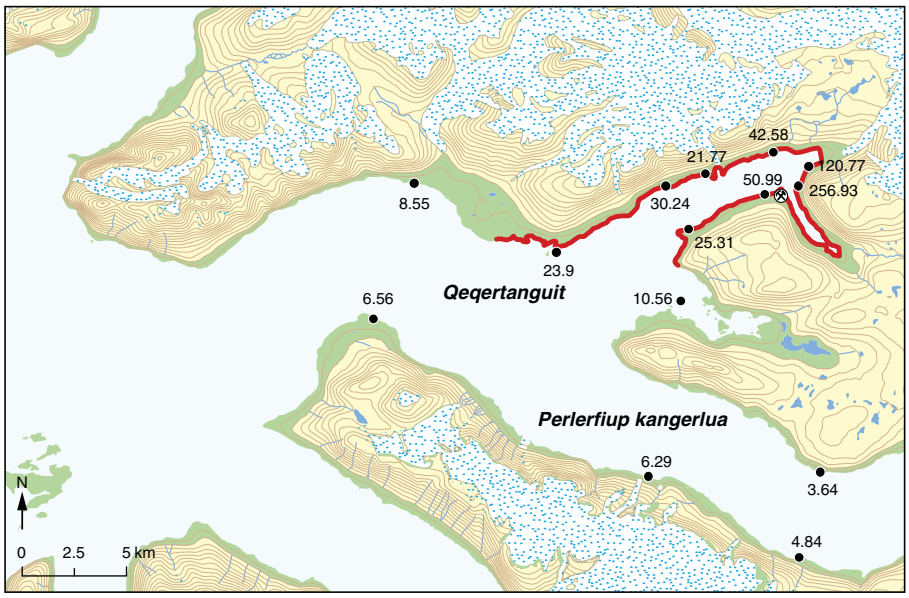


Figure 4.18. Area (marked in red) where it is recommended not to collect and eat blue mussels based on lead concentrations (µg/g dry wt) in large blue mussels

4.4.5 Metallothionein (MT) in blue mussels

In a pilot study the metallothionein (MT) content in blue mussels was measured. The primary purpose of metallothionein in cells is to regulate copper and zinc homeostasis and to detoxify the cell of cadmium and mercury and others. In several studies it has been shown that mussels and fish show an increased MT level after exposure to trace metals. Thus MT level can be used as indicator to document biological effects of metal pollution.

During the sampling in Maarmorilik in 2008, additional mussels were collected together with those for the metal analysis and the MT content was analysed as described in Annex 7.

The highest MT content was measured in mussels from station 12SW, whereas the other stations showed a slightly different pattern depending on the normalisation to the total protein content in the S30 fraction. The high MT content in mussels from station 12SW corresponds with the elevated lead and zinc content measured in blue mussels. Here the lead concentration was 227-257 µg dry wt and the zinc concentration 418-474 µg dry wt. At station L the lead concentration was 2.4 µg dry wt and the zinc concentration 132 µg dry wt. At St. 17 the lead concentration was 73-100 µg dry wt and the zinc concentration 179-249 µg dry wt. The baseline lead concentration in blue mussels is about 1 µg dry wt. This indicates that the metal contamination only introduces a MT effect at very high lead levels and not at levels elevated by a factor of 100 as is seen at St. 17.

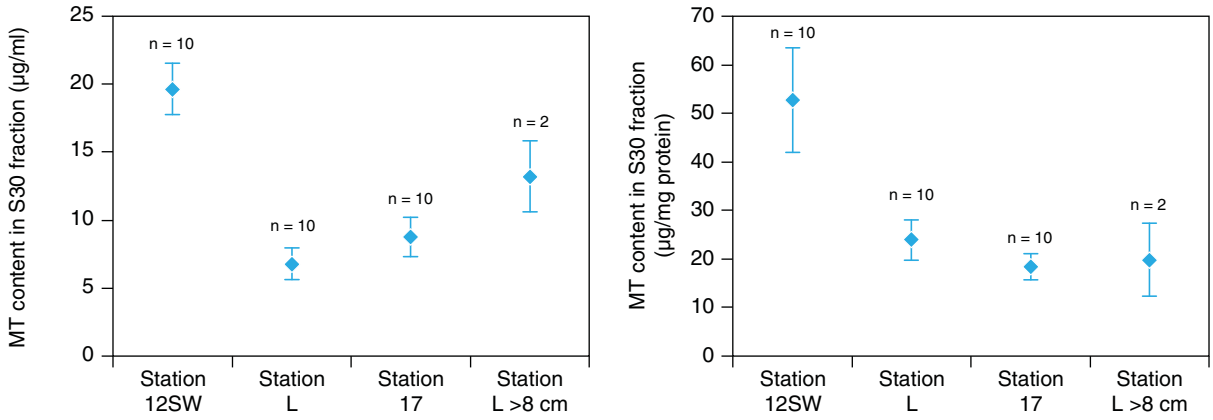


Figure 4.19. Metallothion (MT) content in digestive glands from blue mussels from 4 different stations around Maarmorilik in 2008 a) without normalisation and b) with normalisation to the total protein content in the S30 fraction.

4.5 Shorthorn sculpin

Shorthorn sculpin (*Myoxocephalus scorpius*) is a common, rather stationary fish species, and therefore a suited indicator to assess spatial and temporal trends of contamination from the mine in fish. Only lead has been analyzed, since in previous year it was the only metal which was elevated.

A time trend analysis of lead concentration in sculpin was conducted using the same method as described in section 4.3.2. The log-median lead concentration is used as the annual index value instead of log-mean because of the occurrence of concentrations below detection limit. The results are shown in Table 4.10 and Figure 4.20.

In muscle tissue lead concentrations are not elevated compared to the reference site and there is no trend over time. 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 in shorthorn sculpin from the reference station, but they are still elevated (approximately a factor 2) and significantly higher both for liver ($p=0.016$) and bone ($p=0.017$) compared to 2005. The test were performed in a 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 are 0.2 µg/g (wet wt) for fish meat and 0.3 µg/g (wet wt) 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 4.20).

Table 4.10. 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, 1988-2008[1]	sign	-	-7.9%	sign	-	-9.9%	-	-	8.2%
Muscle, 1988-2007[1]	-	-	+2.7%	-	-	-1.5%	-	-	7.8%
Bone, 1988-2007[1]	-	-	-6.0%	sign	-	-9.6%	-	-	15.0%

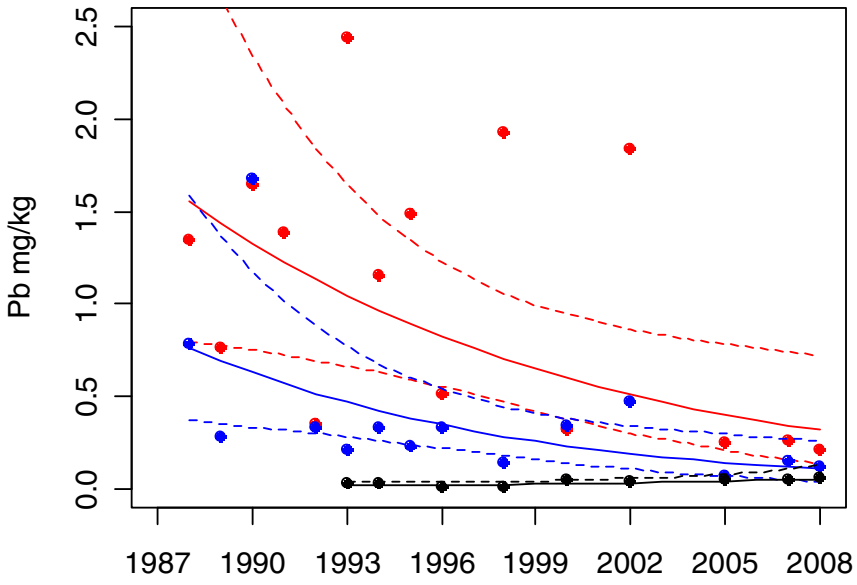


Figure 4.20. Temporal trend of lead concentrations in shorthorn sculpin liver. Red colour denotes Inner Qaamarujuk, blue colour Outer Qaamarujuk and black colour reference site. Points and solid trend line together with 95% confidence broken lines are given.

4.6 Northern shrimp

Northern shrimp (*Pandalus borealis*) is another indicator used to assess spatial and temporal trends of the contamination from the mine. As in fish, only lead was analyzed, since it was the only metal which was elevated in previous years. The shrimps were divided into length groups, each consisting of two types of samples: 1. the meat and 2. 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 4.3.2. The log-median lead concentration is used as the annual index value. The results are shown in Table 4.11 and Figure 4.21.

Table 4.11. 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, 1988-2008	sign	sign	-4.9%	sign	sign	-4.7%	sign	sign	8.0%
Meat, 1988-2008	-	-	-2.1%	sign	-	-6.4%	sign	-	8.3%

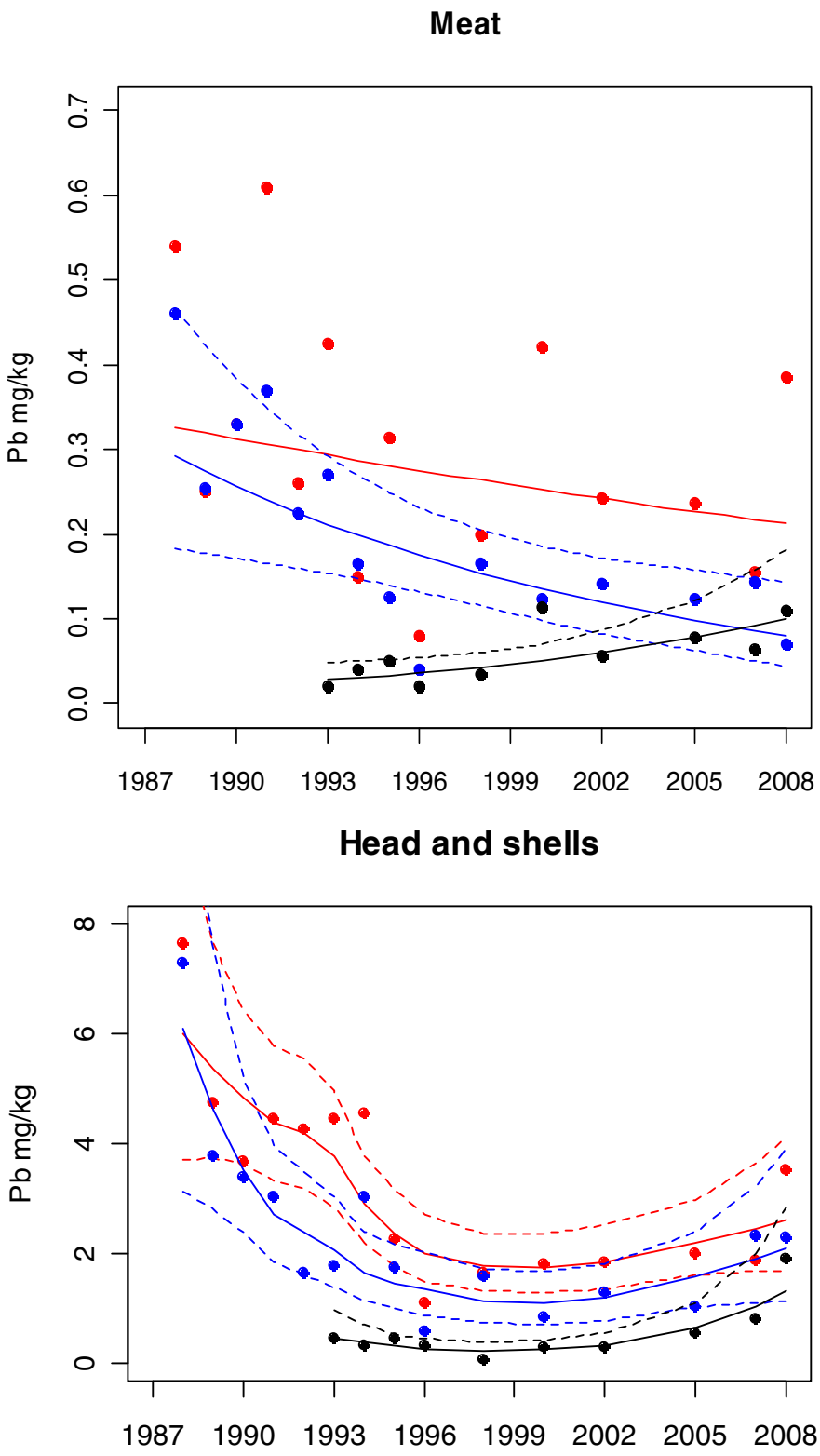


Figure 4.21. Temporal trend of lead concentrations in northern shrimp in the Inner Qaamarujuk fjord (red dots) Outer Qaamarujuk fjord (blue dots) and reference site (black dots). Points and solid trend line together with 95% confidence broken lines are given when significant trend was found in the temporal trend analysis. Points and solid line are given when no significant trend was found.

Over the whole monitoring period 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 in the Inner Qaamarajuk concentrations are significantly higher than at the reference site ($p=0.04$), but not in the Outer Qaamarajuk ($p=0.10$). Lead concentrations in meat are significantly elevated in Inner Qaamarujuk ($p<0.01$) but not in Outer Qaamarujuk ($p=0.35$). The test was 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 the Inner and Outer Qaamarujuk.

The "maximum allowed level" for lead in Greenlandic diet items is 0.5 µg/g (wet wt) for shellfish (Anon. 2005). This value is equal to about 2 µg/g (dry wt). Compared to the "maximum allowed level", the levels found in shrimp meat are well below (Figure 4.21).

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Annex 1. Metal analyses of lichens in 2008 transplanted from Saatut in 2007

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

ID #	Station	Pb	Zn
39452	T6	4.49	23.49
39452	T6	4.96	17.76
39453	T12SW	164.59	267.63
39454	T12Ø	52.63	85.75
39455	T17A	4.50	16.76
39456	T17B	10.10	25.32
39457	T22	11.27	21.55
39458	T25	2.78	13.56
39459	T30	2.97	19.06
39460	T36	2.24	16.12
39461	V	1.01	11.03
39462	G	1.48	23.71
39463	L	0.31	12.28
39464	Saattut	0.69	12.56

Annex 2. Metal concentrations in seawater

Results are in µg/L. Detection limits are shown in the last row.

	Depth m	Zn	Cd	Pb
St . 1 28 August	2	9.81	0.0230	0.0760
	10	8.45	0.0310	0.1540
	20	5.84	0.0310	0.1500
	30	11.70	0.0930	0.1220
	40	34.74	0.1890	0.4110
	50	41.23	0.2180	0.2820
St . 1 30 August	2	11.53	0.0260	0.0830
	10	4.74	0.0270	0.0690
	20	10.51	0.0480	0.1390
	30	24.04	0.1170	0.1180
	40	29.68	0.2330	0.2140
	50	29.07	0.2450	0.1940
St . 3 30 August	2	9.07	0.0270	0.0320
	10	4.96	0.0290	0.0370
	20	6.10	0.0330	0.0930
	30	12.39	0.0860	0.3650
	40	27.32	0.1880	0.2210
	50	40.13	0.2650	0.5980
St . 3 30 August	2	3.87	0.0300	0.1040
	10	2.37	0.0290	0.0330
	20	2.55	0.5800	0.6700
	30	12.68	0.0850	0.3010
	40	26.50	0.2440	0.3140
	50	36.58	0.2820	0.5470
Reference 30 August	2	13.21	0.0340	0.1260
	10	3.09	0.0110	0.1500
	20	3.00	0.0270	0.1540
	30	4.38	0.0370	0.2310
Detection limit		***0.052***	***0.007***	***0.014***

Annex 3. Metal concentration in seaweed

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

ID #	Station	Species	Pb	Zn
39321	T2	*Fucus vesiculosus*	1.35	60.20
39322	T2	*Fucus vesiculosus*	1.06	52.84
39323	T3	*Fucus vesiculosus*	0.66	36.61
39324	T3	*Fucus vesiculosus*	0.69	39.15
39325	T5	*Fucus vesiculosus*	1.23	47.17
39326	T6	*Fucus distichus*	0.54	22.10
39327	T10	*Fucus vesiculosus*	1.79	68.77
39328	T10	*Fucus vesiculosus*	3.96	115.86
39301	T12SW	*Fucus vesiculosus*	6.00	75.51
39302	T12SW	*Fucus vesiculosus*	6.79	100.42
39303	T12Ø	*Fucus vesiculosus*	11.17	115.26
39304	T12Ø	*Fucus vesiculosus*	14.29	216.12
39305	T15	*Fucus vesiculosus*	2.94	104.15
39306	T15	*Fucus vesiculosus*	3.23	99.85
39306	T15	*Fucus vesiculosus*	3.22	97.13
39307	T15A	*Fucus vesiculosus*	1.56	66.76
39308	T15A	*Fucus vesiculosus*	2.95	90.61
39329	T17	*Fucus vesiculosus*	2.96	72.19
39330	T17	*Fucus vesiculosus*	2.91	75.86
39408	T17A	*Fucus vesiculosus*	1.98	53.80
39409	T17A	*Fucus vesiculosus*	1.61	46.97
39331	T17B	*Fucus vesiculosus*	3.17	77.95
39332	T17B	*Fucus vesiculosus*	3.68	77.92
39333	T17C	*Fucus vesiculosus*	3.91	71.86
39334	T17C	*Fucus vesiculosus*	2.71	63.70
39410	T22	*Fucus vesiculosus*	1.01	39.24
39411	T22	*Fucus vesiculosus*	0.95	35.45
39413	T25	*Fucus vesiculosus*	0.73	27.21
39412	T25	*Fucus vesiculosus*	0.73	26.71
39414	T29	*Fucus vesiculosus*	0.94	37.93
39415	T29	*Fucus vesiculosus*	0.80	39.30
39416	St. 30	*Fucus vesiculosus*	1.19	41.07
39417	St. 30	*Fucus vesiculosus*	1.14	38.64
39438	St. 33	*Fucus vesiculosus*	0.45	15.84
39439	St. 33	*Fucus vesiculosus*	0.33	15.06
39440	St. 36	*Fucus vesiculosus*	0.97	23.51
39441	St. 36	*Fucus vesiculosus*	0.90	21.58
39386	St. 37	*Fucus distichus*	0.81	27.16
39387	St. 37	*Fucus distichus*	0.58	28.08

39388	St. 38	*Fucus distichus*	0.37	11.24
39389	St. 38	*Fucus distichus*	0.58	12.57
39389	St. 38	*Fucus distichus*	0.52	11.95
39317	St. L	*Fucus vesiculosus*	0.27	9.67
39382	St. G	*Fucus distichus*	0.34	11.59
39383	St. G	*Fucus distichus*	0.49	12.68
39380	St. F	*Fucus distichus*	0.28	21.17
39381	St. F	*Fucus distichus*	0.50	13.33
39384	St. V	*Fucus distichus*	0.39	10.63
39385	St. V	*Fucus distichus*	0.31	9.80

Annex 4. Metal concentration in blue mussels

Soft tissue was analyzed. Results are in µg/g dry weight. Numbers in italic refer to level in transplanted mussels.

ID #	Station	Size group	Number of individuals	Mean individual weight (g wet wt)	Dry wt %	Pb µg/g dry wt	Zn µg/g dry wt
39437	T1	5-6 cm	20	4.4	11.30	209.50	429.02
39335	T2	4-5 cm	20	4.9	14.30	47.71	157.33
39336	T2	5-6 cm	20	7.3	13.22	73.25	163.15
39337	T3	4-5 cm	20	5.0	14.74	23.52	161.96
39338	T3	5-6 cm	20	7.7	13.12	43.37	193.78
39339	T5	4-5 cm	20	5.0	13.91	31.21	134.51
39316	T5	6-7 cm	20	5.4	13.91	32.17	136.04
39340	T5	5-6 cm	20	8.0	13.41	41.84	163.24
39341	T6	4-5 cm	17	6.3	14.33	17.83	123.00
39342	T6	6-7 cm	13	9.7	14.56	20.29	170.22
39343	T10	4-5 cm	20	3.8	11.70	81.76	200.08
39344	T10	5-6 cm	20	6.4	11.28	127.98	191.20
39311	T12Ø	5-6 cm	20	4.4	15.41	180.85	444.07
39312	T12Ø	6-7 cm	19	6.4	14.12	258.51	539.03
39309	T12SW	5-6 cm	18	4.5	14.18	226.56	473.83
39310	T12SW	6-7.7 cm	18	4.5	23.67	256.93	417.58
39313	T15	5-6 cm	20	3.6	13.29	110.98	335.96
39314	T15	6-7 cm	20	6.3	13.56	120.77	243.86
39315	T15A	5-6 cm	20	3.5	13.94	93.21	305.16
39316	T15A	6-7 cm	20	5.4	13.30	108.54	297.98
39316	T15A	6-7 cm	20	0.0	13.30	106.49	299.48
39345	T17	4-5 cm	20	4.2	12.69	72.60	179.11
39346	T17	5-6 cm	20	5.4	11.52	99.82	248.71
39399	T17A	5-6 cm	20	nd	13.92	36.62	116.62
39400	T17A	6-7 cm	20	nd	13.98	42.58	139.07
39347	T17B	4-5 cm	20	4.2	13.43	66.91	123.53
39348	T17B	5-6 cm	20	5.3	13.36	96.18	166.64
39349	T17C	4-5 cm	20	3.5	11.90	96.81	294.57
39350	T17C	5-6 cm	20	6.0	10.83	92.92	200.14
39300	T22	4-5 cm trans	7	5.6	11.46	*16.40*	*191.01*
39402	T22	5-8,4 cm trans	14	5.3	11.53	*13.75*	*175.54*
39298	T22	5-6 cm	20	4.7	13.26	48.57	165.56
39299	T22	6-7 cm	20	6.5	13.78	50.99	132.16
39401	T25	5-6 cm	20	4.2	13.55	17.64	126.68
39403	T25	6-7 cm	20	6.1	13.38	25.31	150.35
39404	T29	5-6 cm	20	4.5	13.80	34.62	149.09
39405	T29	6-7 cm	20	5.9	14.06	30.24	143.02
39406	T30	5-6 cm	20	3.7	14.36	29.33	112.27
39407	T30	6-7 cm	20	6.9	14.00	21.77	100.28
39430	T33	5-6 cm	9	5.1	14.58	6.31	96.28

39431	T33	6-7 cm	20	6.6	13.63	10.56	109.36
39432	T36	5-6 cm	20	3.9	8.57	20.36	122.67
39433	T36	6-7 cm	20	5.3	15.25	23.90	116.00
39435	T36	4-5 cm	20	2.2	7.17	7.79	188.65
39436	T36	5-6 cm trans	19	3.6	13.98	*7.34*	*205.25*
39434	T36	6-8,2 cm trans	6	9.0	10.74	*8.03*	*190.52*
39395	T37	5-6 cm	20	4.1	14.31	7.53	98.12
39395	T37	5-6 cm	20	4.1	14.31	7.02	95.90
39396	T37	6-7 cm	20	6.0	12.97	8.55	117.70
39397	T38	5-6 cm	20	4.9	14.73	4.52	145.42
39398	T38	6-7 cm	20	7.0	13.82	6.56	151.88
39390	F	5-6 cm	15	5.8	16.64	3.87	170.31
39391	F	6-7 cm	20	9.0	15.95	4.84	138.75
39392	G	5-6 cm	20	5.0	13.84	4.43	115.24
39393	G	6-7 cm	20	7.1	13.77	6.29	140.90
39394	V	6-8 cm	13	12.4	16.36	3.64	112.73
39318	L	4-5 cm	20	2.2	14.45	2.41	131.87

Annex 5. Lead concentration in 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 wt (%)	Pb
33319	IQ	54.0	2140	F	Liver	35.00	0.151
33320	IQ	50.0	1550	M	Liver	27.72	0.238
33351	IQ	31.5	400	F	Liver	33.51	0.343
33352	IQ	33.0	420	F	Liver	36.73	0.170
33353	IQ	34.0	490	F	Liver	35,96	-0.006
33354	IQ	33.0	520	F	Liver	37.21	-0.008
33355	IQ	33.0	440	F	Liver	25.27	0.004
33356	IQ	30.0	340	F	Liver	37.97	-0,008
33357	IQ	26.0	200	F	Liver	31.91	0.183
39358	IQ				Liver	31.47	0.325
39358	IQ	32.0	411	F	Liver	31.47	0.288
39359	IQ	33.0	516	F	Liver	34.43	0.146
39360	IQ	35.0	604	F	Liver	30.05	0.183
39361	IQ	34.0	653	F	Liver	31.62	0.109
39362	IQ	36.0	727	F	Liver	27.95	0.245
39363	IQ	31.0	412	F	Liver	25.31	0.249
39364	YQ	35.0	583	F	Liver	35.33	0.147
39365	YQ	37.0	715	F	Liver	33.58	0.149
39366	YQ	38.0	735	F	Liver	36.76	0.119
39367	YQ	36.0	684	F	Liver	33.04	0.227
39368	YQ	37.0	685	F	Liver	27.13	0.152
39369	YQ	39.0	779	F	Liver	30.82	0.295
39370	YQ	34.0	735	F	Liver	36.81	0.085
39371	YQ	38.0	721	F	Liver	39.53	0.066
39371	YQ	38.0	721	F	Liver	39.53	0.067
39372	YQ	35.0	620	F	Liver	37.78	0.066
39373	YQ	36.0	600	F	Liver	38.80	0.098
39374	YQ	32.0	525	F	Liver	32.71	0.098
39375	YQ	33.0	543	F	Liver	31.09	0.160
39376	YQ	35.0	543	F	Liver	28.43	0.212
39377	YQ	33.0	511	F	Liver	36.28	0.050
39378	YQ	33.0	372	F	Liver	30.33	0.123
39418	Ref	30.0	433	F	Liver	27.70	0.090
39419	Ref	23.0	131	F	Liver	30.08	0.115
39420	Ref	22.5	151	F	Liver	25.00	0.044
39421	Ref	26.0	218	F	Liver	29.04	0.061
39422	Ref	32.0	518	F	Liver	23.32	0.091
39423	Ref	23.5	172	F	Liver	24.59	0.050
39424	Ref	24.0	170	F	Liver	21.93	0.036
39425	Ref	22.5	177	F	Liver	27.48	0.044

Annex 6. Lead concentration in Northern shrimp

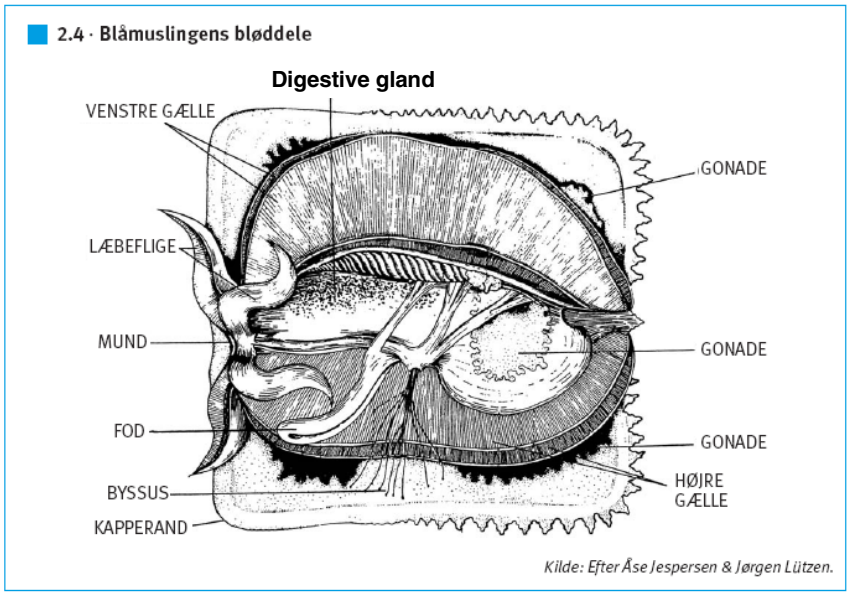
Results are in µg/g dry weight. Ref: reference site, YQ: Outer Qaamarujuk, IQ: Inner Qaamarujuk, H+S: heads and shells.

ID #	Area	Tissue	Length group	Number of individuals	Mean individual weight (g/wet wt)	Dry wt (%)	Pb
39428	Ref	H+S	21-27 mm	8	7.2	19.24	1.99
39426	Ref	H+S	15-21 mm	18	3.3	18.26	1.80
39297	YQ	H+S	>22 mm	9	8.8	21.02	2.17
39295	YQ	H+S	19-22 mm	24	4.9	20.47	1.93
39293	YQ	H+S	17-19 mm	20	3.6	21.03	2.98
39291	YQ	H+S	<17 mm	40	2.6	20.76	2.42
39285	IQ	H+S	>22 mm	8	9.0	23.07	2.67
39284	IQ	H+S	19-22 mm	9	5.5	20.32	3.16
39283	IQ	H+S	17-19 mm	25	3.4	21.47	3.91
39282	IQ	H+S	<17 mm	50	2.1	21.14	4.94
39429	Ref	Kød	21-27 mm	8	7.2	14.65	0.15
39427	Ref	Kød	15-21 mm	18	3.3	14.59	0.07
39296	YQ	Kød	>22 mm	9	8.8	19.31	0.01
39294	YQ	Kød	19-22 mm	24	4.9	19.12	0.06
39292	YQ	Kød	17-19 mm	20	3.6	19.09	0.08
39290	YQ	Kød	<17 mm	40	2.6	18.92	0.51
39289	IQ	Kød	>22 mm	8	9.0	19.44	0.18
39288	IQ	Kød	19-22 mm	9	5.5	19.40	0.23
39287	IQ	Kød	17-19 mm	25	3.4	19.14	0.54
39286	IQ	Kød	<17 mm	50	2.1	19.23	1.39

Annex 7. Metallothionein (MT) contents in blue mussels from Maarmorilik 2008

Sampling protocol and preservation of the digestive gland from *Mytilus edulis* for metallothionein (MT) analyses, Maarmorilik 2008.

1. Mark the Eppendorf tubes, both at the side and at the top.
2. Open the mussel by cutting the adductor muscles with a scalpel.
3. Take out carefully the whole soft body of the mussel.
4. Use a scissor to cut free the brownish digestive gland. Remove other tissue types as possible.
5. Measure the total weight of the digestive gland in an Eppendorf tube. (Zero the weight with an empty Eppendorf tube)
6. Cut the digestive gland into smaller pieces inside the Eppendorf tube.
7. Add about 0.5 ml Preservation Liquid (AllTissueProtect agent, with 5 mM mercaptoethanol and EDTA) for ~0.1 g tissue wet weight. Remove tissue, if more than 0.2 g ww.
8. Shake the sample by hand for 15 sec, and check that all the tissue is covered by liquid.
9. Let the tissue equilibrate in the preservation liquid for 1 hour in a refrigerator at +5°C.
10. After 1 hour equilibration, store all the samples in a freezer at -20°C.



Sample preservation and storage

About 0.3 g of digestive gland from individual blue mussels (*Mytilus edulis*) was cut into smaller peaces and preserved in about 1.5 ml protein preservation liquid (AllTissueProtect agent, with 5 mM mercaptoethanol and EDTA). The tissue was equilibrated in the preservation liquid for 1 hour in a refrigerator at +5°C and after 1 hour equilibration, all the samples were store in a freezer at -20°C for about 2 month until the arrival to

the laboratory in Denmark. After the arrival the sample were moved for storage at -80°C.

Metallothionein (MT) analyses

The samples were centrifuged at 30.000 g for 5 min at 4°C. After tissue homogenisation and extraction of protein into a phosphate buffer (pH = 8.0) with a pestil.

The MT content in the supernatant fraction (S30) was determined according to the manual on the biomarkers recommended for the MED POL biomonitoring programme using Ellman's reagent (UNEP, 1999). The MT content can be measured spectrophometric at 412 nm in a partially purified metallothionein fraction (Figure 1A), because of the reaction of DTNB with sulphyhydryl groups. As known, metallothioneins are characterised by extremely high cystein content, when compared to other proteins eventually present in the purified ethanolic extracts. The quantification was done by external calibration to glutathione (GSH) (Figure 1A).

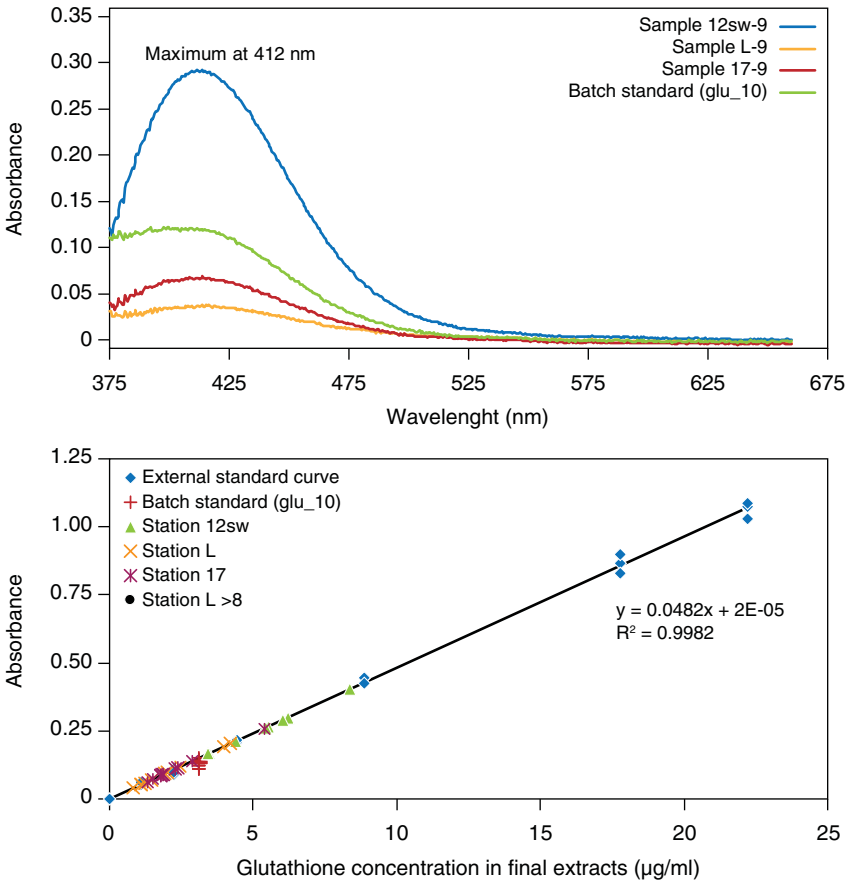


Figure A1. a) UV-VIS spectra of the MT content in three representative mussel samples compared with a glutathione standard of 3 nmol/ml; b) Standard curve for external calibration compared with absorbance of the MT content in final extracts of all mussel samples from the four stations.

The total protein content in the S30 fraction is used for normalisation of the MT content in the samples.

The total protein content is determined using Bradford reagent and a plate reader measuring the absorbance at 590nm.

Table A1. MT concentration in individual mussels from 4 stations at Maarmorilik in West Greenland, August 2008.

	Station 12SW		Station L		Station 17		Station L > 8 cm	
Id. Nr	**µgMT /ml**	**µgMT /mg protein**	**µgMT /ml**	**µgMT /mg protein**	**µgMT /ml**	**µgMT /mg protein**	**µgMT /ml**	**µgMT /mg protein**
1	32.2	36.6	7.8	12.0	8.7	11.6	10.6	12.4
2	20.8	32.0	7.4	33.7	20.7	32.2	15.8	27.3
3	21.3	103.1	15.4	44.1	5.0	12.5		
4	13.3	24.2	6.2	11.8	7.2	17.8		
5	23.8	59.6	9.6	29.3	6.8	16.6		
6	13.1	26.8	5.3	38.2	9.0	10.6		
7	16.7	27.5	4.7	28.4	10.9	15.0		
8	13.1	22.3	4.2	25.5	6.7	10.7		
9	23.0	105.7	3.1	9.0	5.7	24.7		
10	18.8	89.4	4.2	7.3	7.0	32.0		
Average	19.6	52.7	6.8	23.9	8.8	18.4	13.2	19.9
n	10	10	10	10	10	10	2	2
SE	1.9	10.8	1.1	4.1	1.4	2.7	2.6	7.46

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National Environmental Research Institute
Frederiksborgvej 399
PO Box 358
DK-4000 Roskilde
Denmark
Tel: +45 4630 1200
Fax: +45 4630 1114

Management
Department of Arctic Environment
Department of Atmospheric Environment (main address)
Department of Environmental Chemistry and Microbiology
Department of Marine Ecology (main address)
Department of Policy Analysis

National Environmental Research Institute
Vejlsøvej 25
PO Box 314
DK-8600 Silkeborg
Denmark
Tel: +45 8920 1400
Fax: +45 8920 1414

Department of Freshwater Ecology
Department of Marine Ecology
Department of Terrestrial Ecology

National Environmental Research Institute
Grenåvej 14, Kalø
DK-8410 Rønde
Denmark
Tel: +45 8920 1700
Fax: +45 8920 1514

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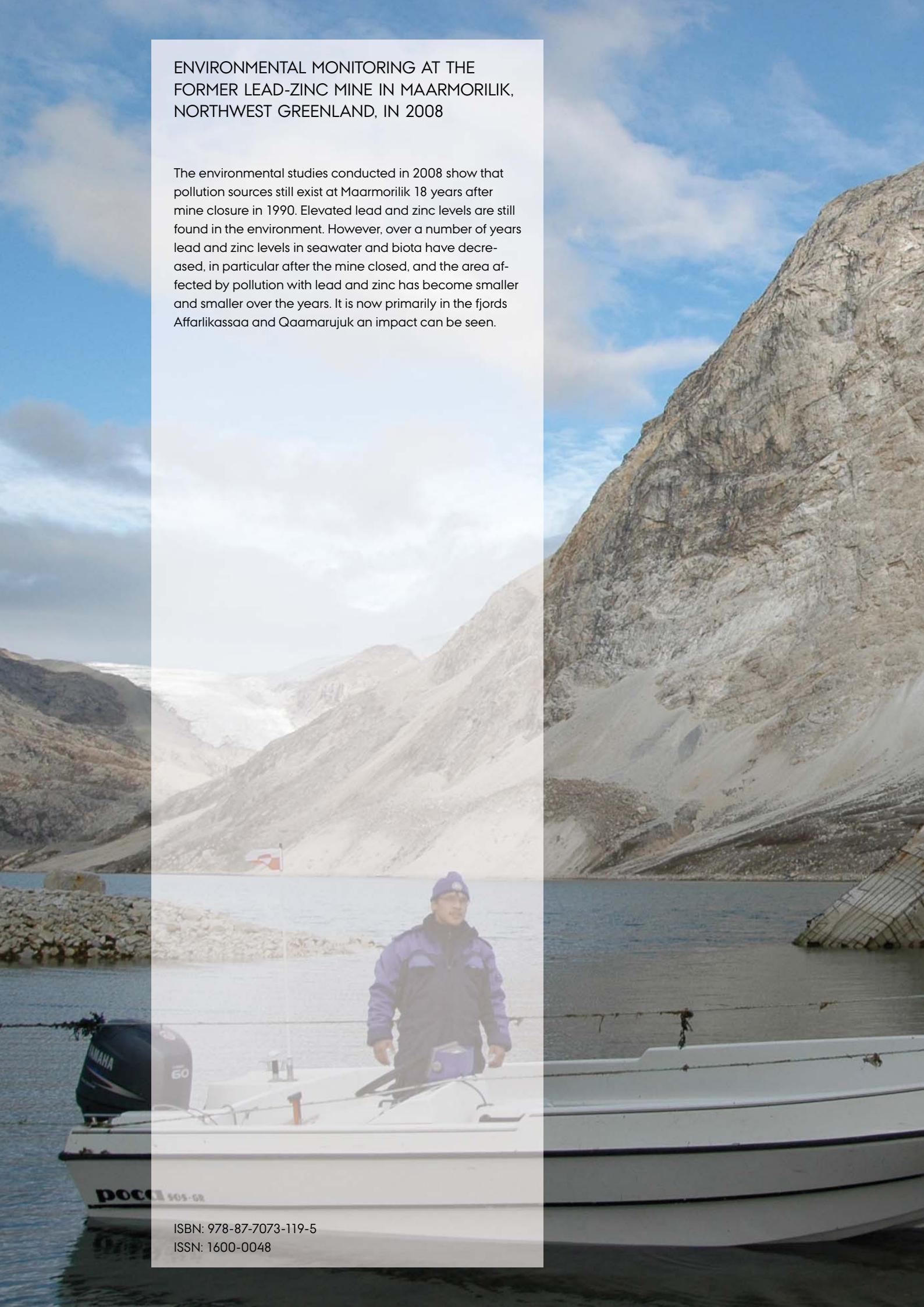

ENVIRONMENTAL MONITORING AT THE FORMER LEAD-ZINC MINE IN MAARMORILIK, NORTHWEST GREENLAND, IN 2008

The environmental studies conducted in 2008 show that pollution sources still exist at Maarmorilik 18 years after mine closure in 1990. Elevated lead and zinc levels are still found 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 the fjords Affarlikassaa and Qaamarujuk an impact can be seen.

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