



ENVIRONMENTAL MONITORING AT THE CRYOLITE MINE IN IVITTUUT, SOUTH GREENLAND, IN 2010

NERI Technical Report no. 812 2010



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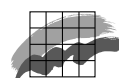
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Data sheet

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Abstract: This report evaluates the pollution in Arsuk Fjord at Ivittuut in South Greenland based on environmental studies conducted in 2010. The area is polluted by lead and zinc caused by the mining of cryolite that took place from 1854 to 1987. The 2010 study shows that the lead pollution of the fjord continues to fall. Zinc concentrations also generally decrease, but slower. We have found elevated lead concentrations in blue mussels in outer Arsuk Fjord and in areas 3-4 km outside the fjord. On a c. 5 km stretch of coastline around Ivittuut, the lead concentration in blue mussels is so high, that it is recommended not to collect and eat mussels. Lead and zinc concentrations in brown seaweed are also elevated in parts of Arsuk Fjord.

Keywords: Ivittuut, cryolite, mining, lead, zinc, seaweed, mussels

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Cover photo: The open pit in Ivittuut is now filled with sea water which has entered though the dam seen to the right. The fjord is seen behind. Photo: Gert Asmund, NERI.

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Contents

English summary 5

Eqikkaaneq 6

Resumé 7

1 Introduction 8

2 Sampling and analyses 10

3 Results and discussion 13

- 3.1 Analytical results and data processing 13
- 3.2 Spatial trends of lead and zinc concentrations 13
- 3.3 Time trends of lead and zinc concentrations 19
- 3.4 Restrictions for eating blue mussels 28

4 Conclusion 30

5 References 31

Annex 1. Brown seaweed data 2010 32

Annex 2. Blue mussel data 2010 33

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English summary

In Ivittuut at Arsuk Fjord in South Greenland the mineral cryolite was mined, sorted and shipped out from 1854 to 1987. The mining operations have caused pollution with lead and zinc in the fjord. The main source is waste rock, which has been left at the coastline and is still releasing lead and zinc to the fjord from tidal water action.

The pollution of the fjord has been monitored since 1982. Since 1985 this monitoring has included only brown seaweed and blue mussels, since earlier studies had shown that fish and prawns from the fjord did not have elevated lead and zinc levels. This report presents the results of the latest environmental study, which was carried out in July 2010.

The geographical pattern of lead and zinc levels found in brown seaweed and blue mussels in 2010 shows that waste rock deposited at the coastline in Ivittuut is still the main source of the pollution of the fjord.

In brown seaweed elevated lead levels were found on a c. 4 km stretch of coastline in eastern Arsuk Fjord around Ivittuut, whereas zinc levels were elevated on most of the coastline studied in Arsuk Fjord. In blue mussels elevated lead levels were seen in all of the studied parts of Arsuk Fjord, and also on coasts 3-4 km outside the fjord. Zinc levels in blue mussels were elevated only at Ivittuut.

Along a stretch of coastline of c. 5 km around Ivittuut the lead concentration in blue mussels is so high that it is recommended not to eat blue mussels from this area. This area is similar to that found in 2007, but smaller than found in 2004 and much smaller than found in the period 1982-1992. During that period it also included part of the western coastline of Arsuk Fjord.

Over the entire monitoring period (1982 to 2010) a decline of lead levels is seen in both brown seaweed and blue mussels in Arsuk Fjord. Lead concentrations have decreased c. 3 times since 1982. Zinc concentrations have also generally decreased, but at a slower rate.

Eqikkaaneq

Ivittuuni Kujataani Arsuup Kangerluani ittumi 1854-imiit 1987-imut orsugiak piiarneqarlunilu, immikkoortiterneqarlunilu aallarussorneqarpoq. Orsugiassiorneq pissutigalugu kangerluk aqerlumik zinkimillu mingutsinneqarsimavoq. Mingutsitsinerup aallaavii tasaanerupput ujaqqat eqqakkat, akuiarnerlukunik taaneqartartut orsugiassiorfimmeer-sut. Ujaqqat taakku Ivittuut sineriaanut nunniutigineqarsimapput. Taakku aqerlumik zinkimillu akoqarput taakkulu arrorlutik ulittarnermit Arsuup Kangerluanut siammarterneqartarlutik.

Tamaani mingutsitsineq 1982-imili malinnaavigineqalerpoq. 1985-imiit qeqqussat (equutit) uillullu kimik malinnaavigineqalerput siusinnerusukkat misissuisarnerni paasinarsereersimammat kangerluup aalisagai raajaalu aqerlumik zinkimillu akunissimanngitsut. Nalunaarusiami matumani misissuineq kingulleq 2010-imi juulimi ingerlanneqar-toq nassuiarneqarpoq.

Akuiarnerlukut (tuluttut taaneqartartut "waste rock") Ivittuut sissaanut qimagarneqarsimasut annerusumik suli mingutsitsisuunerat Qeqqusat uillullu aqerlumik zinkimillu sumiiffinni assigiinngitsuni assigiinngit-sunik akoqassusiisigut malunnarpoq.

Arsuup Kangerluani kangiata tungaani Ivittuut eqqaanni sineriammi 4 kilometerinik isorartutigisumi qeqqussat qaffasinnerusumik aqerlorta-qarput, Arsuulli kangerluani misissuiffiusuni amerlanerpaani qeqqussat qaffasinnerusumik zinkitaqarlutik. Uillut Arsuup Kangerluani misissuif-fiusuni tamani qaffasinnerusumik aqerlorta qarput kiisalu kangerluup avataani aamma sumiiffinni 3-4 kilometerinik ungasissusilinni taamaal-lutik. Ivittuuni namminermit taamaallaat uillut zinkitaqarnerupput.

Ivittuut eqqaanni sineriammi 5 kilometerit missaanni isorartutigisumi uillut ima aqerlorta qartigipput nereqquneqaratik. 2007-imi misissuiner-mi paasisatulli tamanna annertutigaaq 2004-imili misissuinermit anni-kinnerutsiarluni, aammalu 1982-1992-mi nassaarfigineqartumit minneru-jussuulluni. Taamanikkut Arsuup Kangerluata kitaa tungaa aamma ilaa-galuarpoq.

Piffissaq misissuiffiusoq tamaat isigaanni (1982-imiit 2010-mut) Arsuup Kangerluani qeqqussat uillullu aqerlortaat milliartorsimapput. Aqerlo-qassusii 1982-imiit agguaqatigiissillugu pingasoriaammik annikillisi-mapput. Qeqqussat uillullu zinkeqassusiat appariarsimavoq, aqerlulli appariarneratut annertutinngitsumik.

Resumé

I Ivittuut ved Arsuk Fjord i Sydgrønland foregik der brydning, sortering og udskibning af mineralet kryolit i perioden 1854 til 1987. Mineaktiviteterne har bevirket en forurening med bly og zink af fjorden. Hovedkilden er frasorterede sten, såkaldt gråbjerg, fra kryolitbrydningen. Dette materiale er bl.a. efterladt som opfyld langs kysten ved Ivittuut. Det indeholder bly- og zinkminerale, som opløses i og udvaskes af tidevandet til Arsuk Fjord.

Forureningen i området er blevet overvåget siden 1982. Denne overvågning har siden 1985 kun omfattet blæretang og blåmuslinger, idet tidligere undersøgelser havde vist, at fisk og rejer fra fjorden ikke var belastet med bly og zink. Denne rapport redegør for den seneste undersøgelse, som blev udført i juli 2010.

Den geografiske fordeling af bly- og zinkkoncentrationen i blæretang og blåmusling i 2010 viser, at gråbjerg efterladt langs kysten i Ivittuut fortsat er den dominerende forureningskilde.

I blæretang er der forhøjede blyværdier på en ca. 4 km lang kyststrækning i den østlige del af Arsuk Fjord omkring Ivittuut, mens der er forhøjede zinkværdier i blæretang på det meste af kyststrækningen af det undersøgte område i Arsuk fjord. I blåmuslinger er der forhøjede blyværdier i alle undersøgte områder af Arsuk Fjord og også i områder 3-4 km udenfor fjorden. Zinkværdierne i blåmusling er kun forhøjet ved selve Ivittuut.

På en ca. 5 km lang kyststrækning omkring Ivittuut er blykoncentrationen i blåmuslinger så høj, at det frarådes at spise blåmuslinger indsamlet på denne kyststrækning. Dette område er af samme udstrækning som fundet i 2007, men er mindre end fundet ved undersøgelsen i 2004 og meget mindre end fundet i perioden 1982-1992. I denne periode omfattede området også en del af kyststrækningen på den vestlige del af Arsuk Fjord.

Set over hele undersøgelsesperioden (1982 til 2010) er blykoncentrationen i både blæretang og blåmusling faldet i Arsuk Fjord. Blykoncentrationerne er nu i gennemsnit ca. 3 gange lavere end de var i 1982. Zinkkoncentrationen i tang og musling er også faldet, men ikke så meget som blykoncentrationen.

1 Introduction

At the place called Ivittuut in South Greenland, mining for cryolite took place from 1854 to 1987. The mine was an open pit mine located close to the shore in the Arsuk Fjord (Figure 1). The closest settlements are Arsuk, c. 15 km west of Ivittuut, and the Naval Station Grønnedal, c. 5 km northeast of Ivittuut (Figure 1).

Cryolite is an industrial mineral, which is mainly used in aluminium production. The ore was blasted, crushed and sorted on site and subsequently shipped for floatation elsewhere, e.g. in Copenhagen, Denmark.

Environmental studies initiated in 1982 showed that the operation caused pollution with heavy metals, particularly lead and zinc, which are found in the ore material. The most important pollution source has been waste rock, which is disposed at the coastline in Ivittuut. The waste rock contains lead and zinc, which is released as dissolved metals to Arsuk Fjord as the tide moves in and out contacting the waste rock. We have estimated that between 400 and 1,000 kg of dissolved lead annually entered Arsuk Fjord from this source in 1985 (Johansen et al. 1995). Today this amount will be lower. Our results from monitoring seaweed and blue mussels indicate that the amount of lead released could be 3 times lower than in the 1980ies.

In the period from 1982 to 1992, environmental monitoring was conducted each year. Following this period, monitoring was carried out in 1995 and every third year since then. The results from 1982 to 1992 are summarized in Johansen et al. (1995). Results from 1995 are reported in Riget et al. (1995a), results from 1998 in Johansen et al. (1998), results from 2001 in Johansen & Asmund (2003), results from 2004 in Johansen & Asmund (2005) and results from 2007 in Johansen et al. (2008). The first studies showed that the species affected by the heavy metal pollution were brown seaweed (*Fucus vesiculosus*) and blue mussels (*Mytilus edulis*), while fish and prawns from the fjord did not have elevated concentrations of heavy metals. Therefore, since 1985 the environmental monitoring has only included brown seaweed and blue mussels. These two species are suitable indicators because they are sessile and accumulate metals from the surrounding seawater. They therefore reflect the water quality over longer periods of time in the tidal zone, where they live.

In this report we present results from the study conducted at Ivittuut in 2010. We evaluate spatial and temporal trends of lead and zinc pollution within the study area and compare with lead and zinc levels found in these species in uncontaminated regions in Greenland.

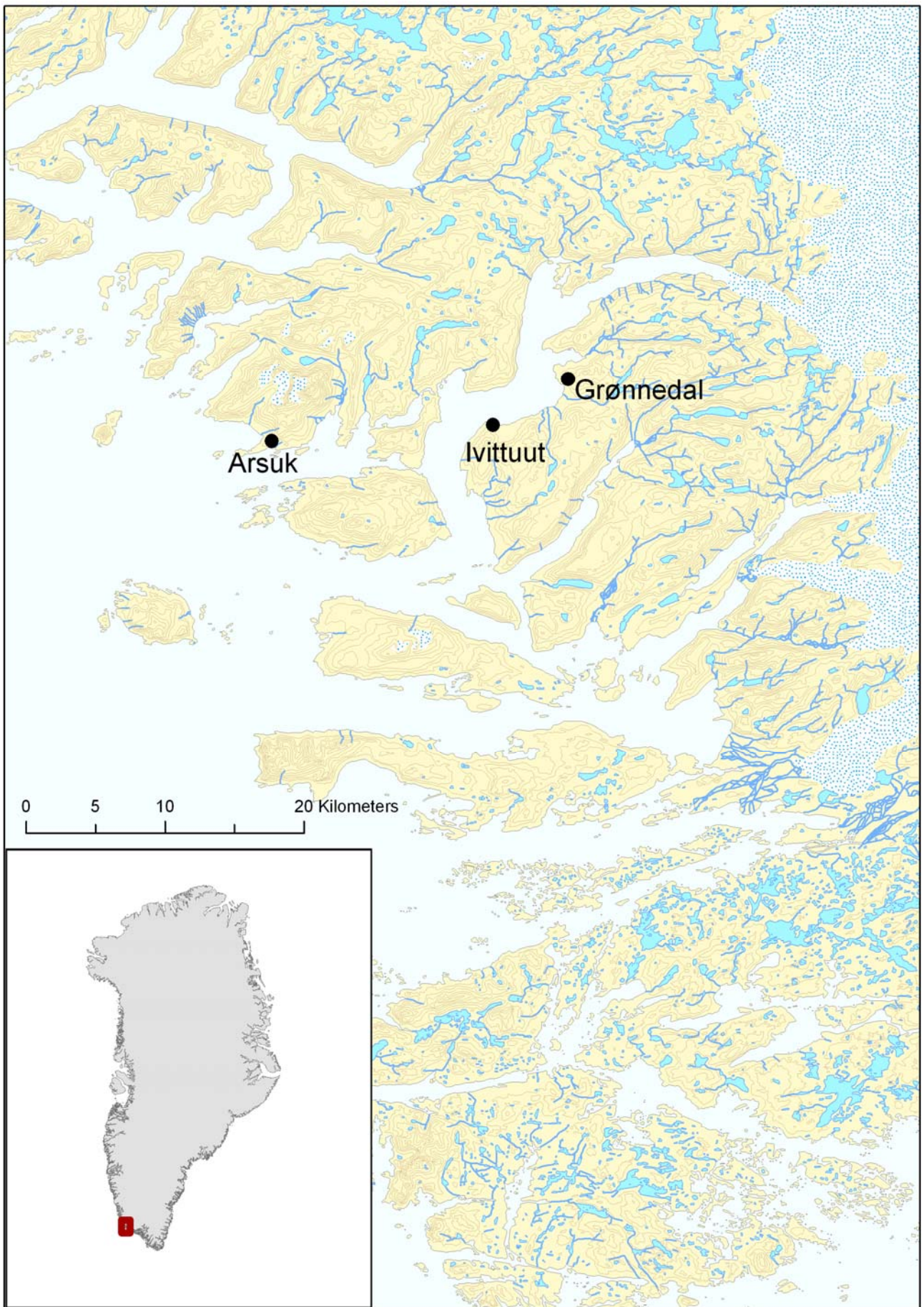


Figure 1. Location of Ivittuut and nearby settlements.

2 Sampling and analyses

Sampling of brown seaweed and blue mussels was conducted in the period 1st July to 4th July 2010 by Sigga Joensen and Lene Bruun from NERI. The study used a boat chartered in the Naval Station Grønnedal, and here the preparation of samples was carried out. Figure 2 shows sampling stations in the area. Not all stations were sampled, but in 2010 sampling stations (see Annex 1 and 2) were identical to stations sampled in 2004 and 2007.

Two samples of brown seaweed (*Fucus vesiculosus*) were collected at 10 to 30 metres distance at each station in order to account for local variation. Growing tips were cut with scissors, rinsed 3 times in clean tap water and frozen.

Blue mussels (*Mytilus edulis*) collected at each station were divided into size classes after their shell length. The adductors of the mussels were cut and the mussels were allowed to drain, before the soft parts of the mussel were cut out of the shell with a stainless steel scalpel. The soft parts of each size group were then frozen.

At the laboratory of the Department of Arctic Environment at NERI (NERI-DAE), the samples of both seaweed and mussels were initially freeze-dried and then ground in an agate mortar. A sub sample of the dried and ground sample was then dissolved with nitric acid in Teflon bombs under pressure in an Anton Paar Multiwave 3000 Microwave Oven. Zinc concentrations were then determined using flame AAS (Perkin Elmer AAnalyst 300) and lead concentrations using graphite furnace AAS (Perkin Elmer AAnalyst 800).

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

The analytical methods were also checked independently by participation 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 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.

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).

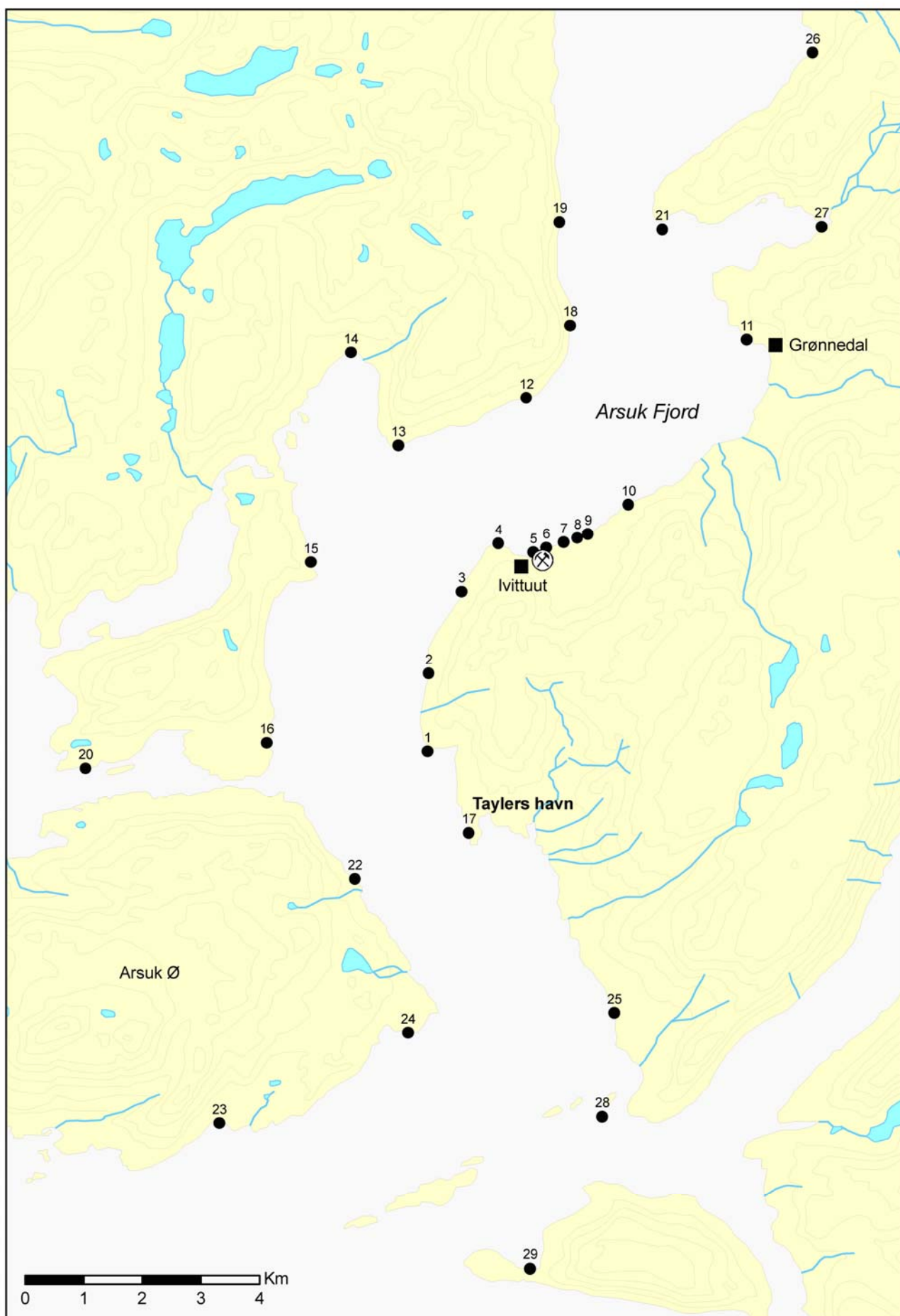
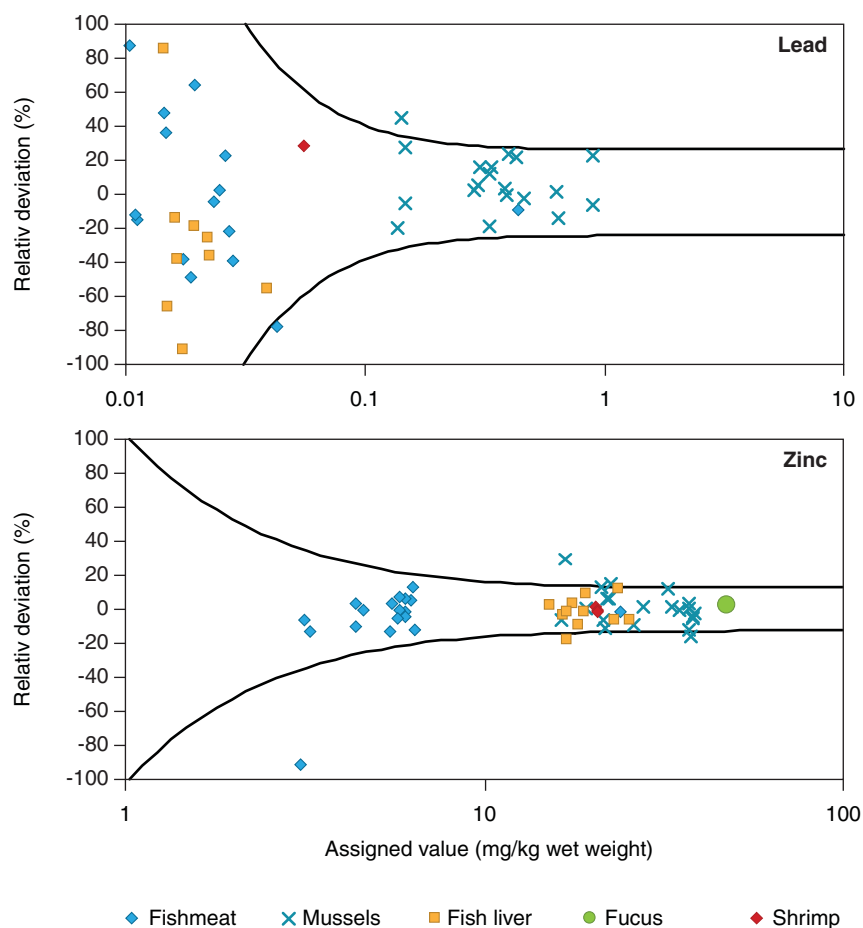


Figure 2. Sampling stations.

Figure 3. Results for lead (above) and zinc (below) from NERI-DAE's participation in the QUASIMEME laboratory study programme. The lines denote the 95% confidence interval for analytical results with detection limits of 1 mg/kg for zinc and 0.03 mg/kg for lead and a relative uncertainty (95%) of 12.5% for zinc and 25% for lead. Samples are not from the Ivittuut area.



Finally the analytical methods were checked by regularly analyzing the same sample twice (same ID# but different nitric acid digestions). In this study, 8 samples were analyzed twice (Annex 1 and 2). The relative deviation was 13.3% for lead and 3.6% for zinc. When a sample has been analyzed twice, we have used the average in further calculations.

3 Results and discussion

3.1 Analytical results and data processing

The data from the 2010 study are shown in Annex 1 (seaweed) and Annex 2 (mussels).

At each station two samples of seaweed were collected at 10 to 30 metres distance for statistical reasons in order to account for local variation. In subsequent presentation and calculation we have used the geometric mean concentration calculated from the two samples.

Earlier studies in Greenland have shown that the lead concentration in blue mussels increases with the size of the mussels, while this is not the case for zinc (Riget et al. 1996). Therefore, in order to be able to compare lead concentrations in the mussels from station to station or from year to year, we have sampled and analyzed typically two size groups: small mussels with a shell length of 2-3 cm and large mussels, in most cases with a shell length of 6-7 cm (Annex 2). The lead results for these two size groups are presented separately in the following sections, while the zinc results are presented as the mean concentration from both size groups at each station.

3.2 Spatial trends of lead and zinc concentrations

3.2.1 Brown seaweed

Metal concentrations in seaweed at the stations sampled in the fjord are shown in Figure 4 (lead) and Figure 5 (zinc). These may be compared with each other and with lead and zinc levels found elsewhere in Greenland. Ideally they should be compared with levels found before mining started, but no such data exist (the mine started operating in 1854). It is likely that lead and zinc levels were elevated locally in the fjords caused by natural release of metals from mineralization. Presumably natural elevated lead and zinc concentrations in seaweed have been found earlier in one area with known a mineralization at Taylers Havn south of Ivittuut, where lead and zinc concentrations in seaweed in the study conducted in 2004 were higher than would be expected from mining pollution alone (Johansen et al. 2005).

In uncontaminated areas in Greenland (areas with no known local sources) we have found lead levels in the range 0.2-0.4 µg/g dry weight and zinc levels in the range 7-17 µg/g dry weight in brown seaweed (Riget et al. 1993, 1995b). Compared to these concentrations, lead levels are elevated in seaweed only within an area of 2 km from Ivittuut. In this area lead concentrations are up to a factor of 100 times higher compared to seaweed in uncontaminated areas (Figure 4). The area affected is much smaller than found earlier.

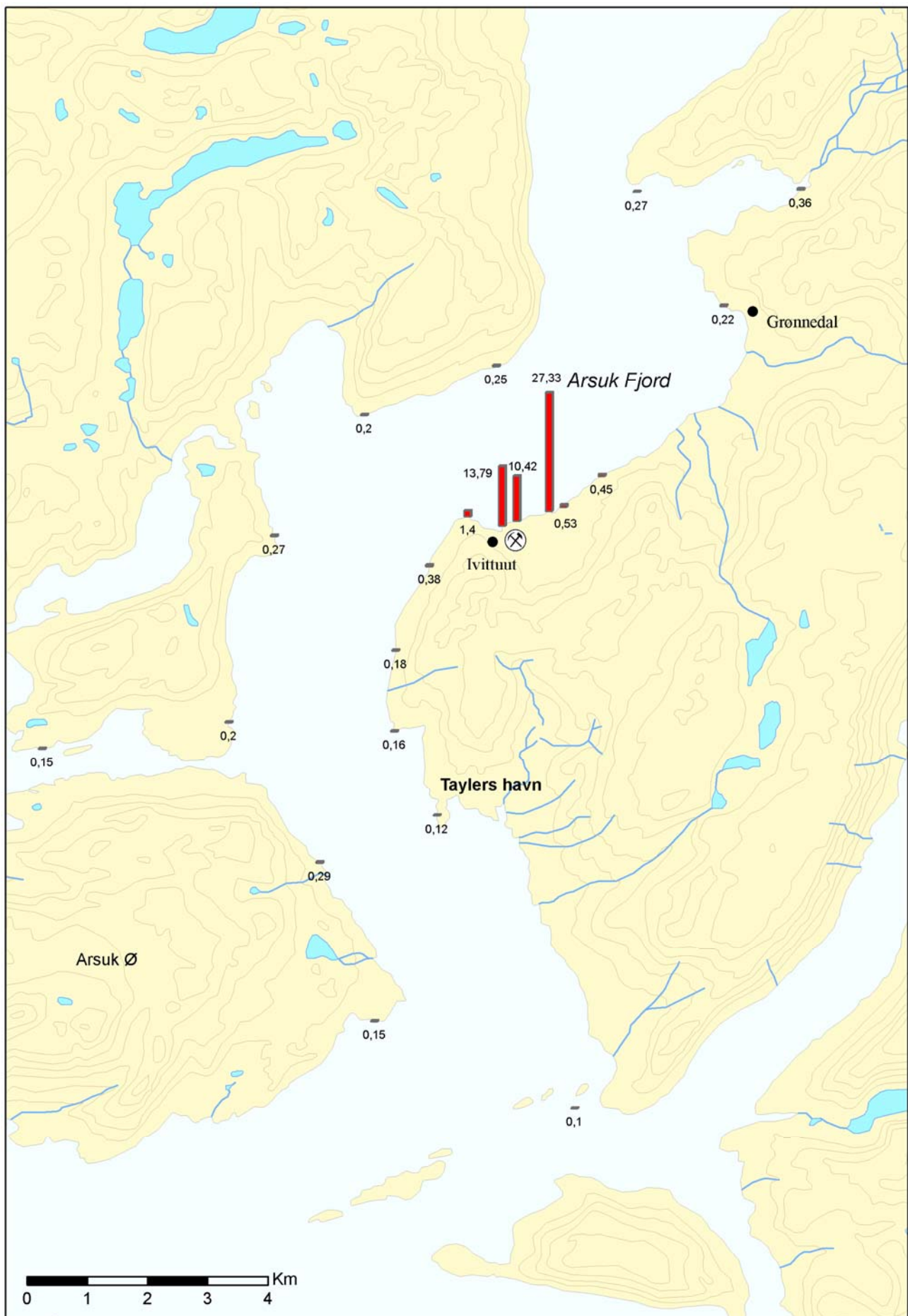


Figure 4. Lead concentration (µg/g dry weight) in brown seaweed (*Fucus vesiculosus*) at Ivittuut in 2010.

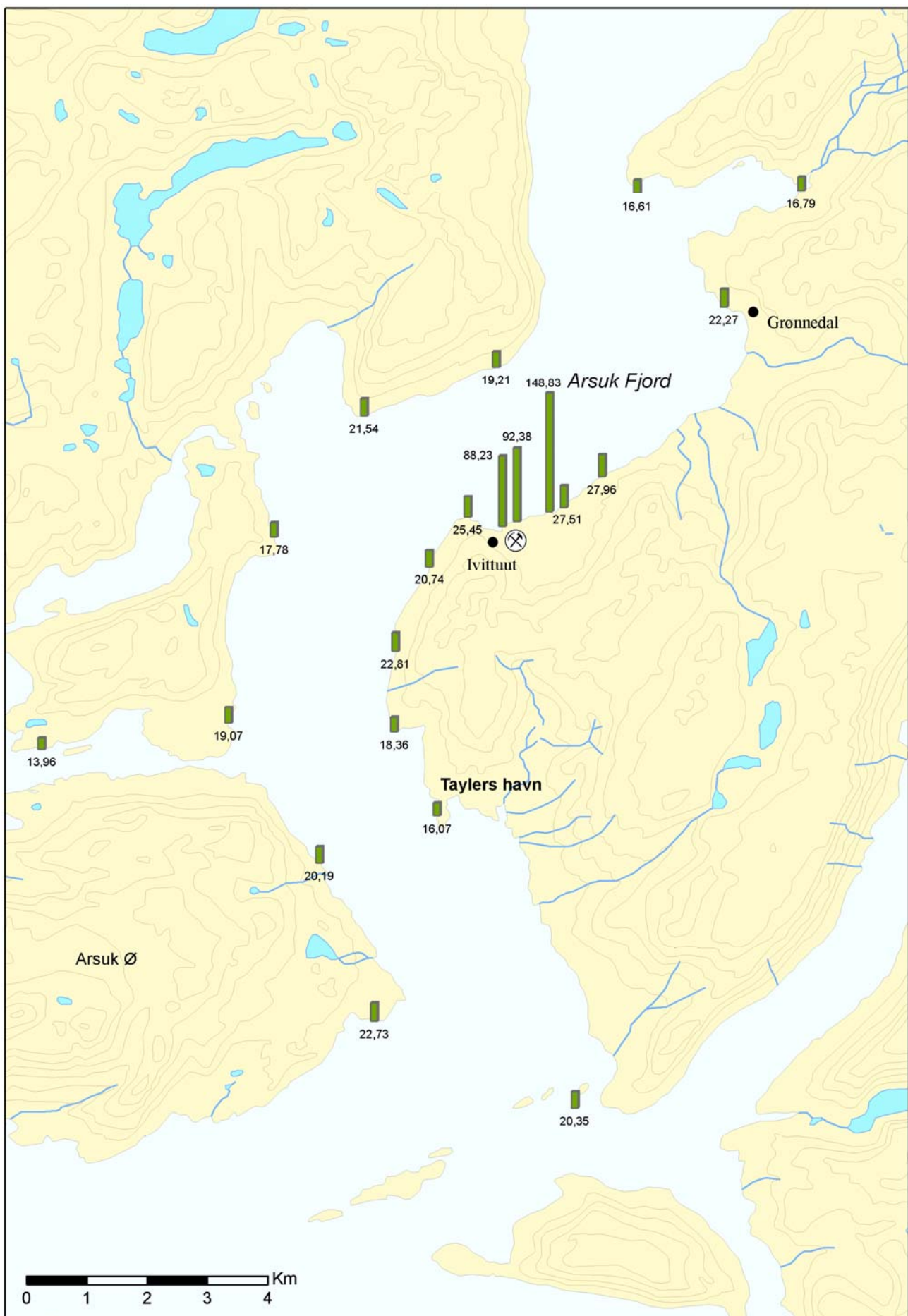


Figure 5. Zinc concentration (µg/g dry weight) in brown seaweed (*Fucus vesiculosus*) at Ivittuut in 2010.

In 2007 elevated lead levels in seaweed were found in most of the fjord surveyed (Johansen et al. 2008). The decrease of lead levels in 2010 in seaweed and of the area affected follows a general decrease observed in the monitoring period (see section 3.3 in this report).

The pattern for the zinc concentration in seaweed is similar to that of lead, except that the area affected is larger and zinc levels are elevated in most of the study area. However, there is no clear geographical trend, except at Ivittuut, where zinc levels are elevated up to 10 times (Figure 5). In 2010 the area affected is smaller than found earlier (Johansen et al. 2008).

3.2.2 Blue mussels

Lead concentrations in blue mussels at the stations sampled in the fjord are shown in Figure 6 (small mussels) and Figure 7 (large mussels). Zinc concentrations in mussels are shown in Annex 2. As with seaweed, the levels from Arsuk Fjord may be compared with each other and with lead and zinc levels found elsewhere in Greenland. In blue mussels from Greenland areas with no known local pollution sources we have found lead and zinc concentration as shown below (Riget et al. 1993, Aarkrog et al. 1997):

Shell length	Lead (µg/g dry weight)	Zinc (µg/g dry weight)
2-3 cm	0.7-0.9	80-100
>6 cm	0.7-1.7	80-100

Figure 6 and 7 show that lead concentrations are exceeded in the whole study area, that is in most of Arsuk Fjord, but also in areas outside the fjord north and south of the island of Arsuk. Even on the island Napasut (station 29), about 15 km south of Ivittuut, lead levels are elevated about 2 times. In most of the other areas, including Arsuk Fjord, lead levels are elevated 3-4 times. The highest levels are found at Ivittuut where levels are elevated 200-800 times. Zinc concentrations in blue mussels were elevated only at station 5 and 8 at Ivittuut and only by a factor up to about 2.

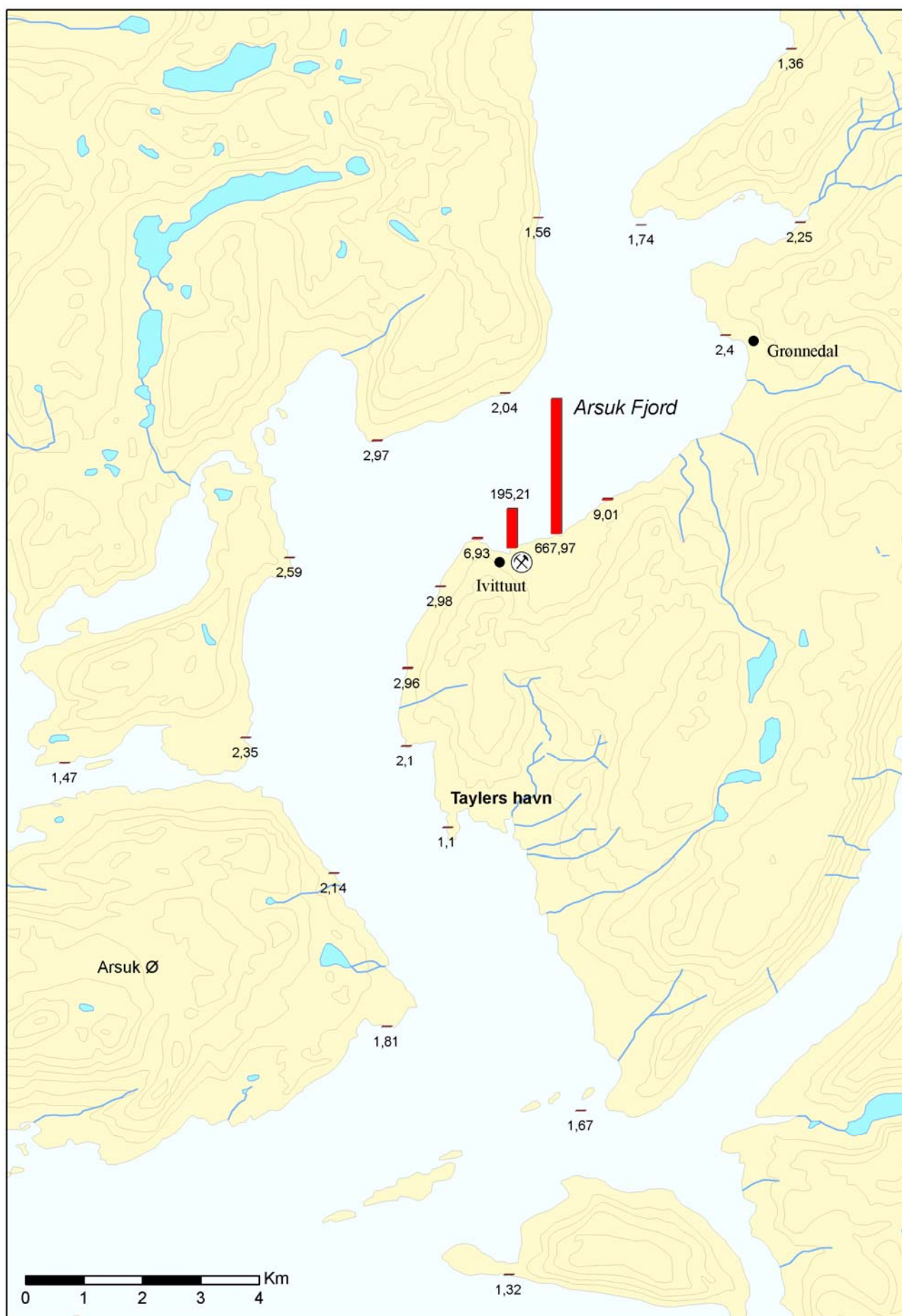


Figure 6. Lead concentration ($\mu\text{g/g}$ dry weight) in small blue mussels (*Mytilus edulis*, 2-3 cm shell length) at Ivittuut in 2010.

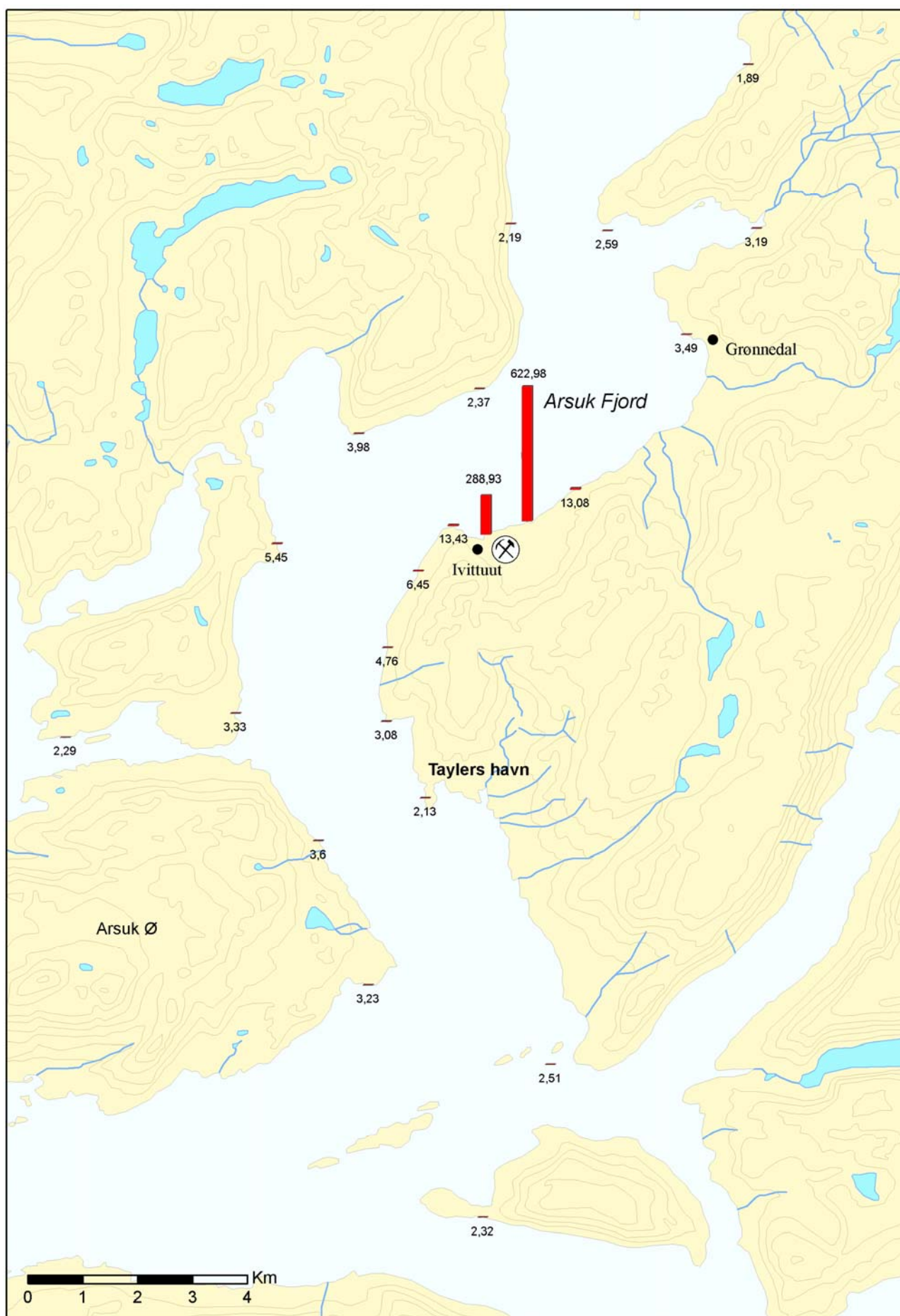


Figure 7. Lead concentration (µg/g dry weight) in large blue mussels (*Mytilus edulis*, >6 cm shell length) at Ivittuut in 2010.

3.3 Time trends of lead and zinc concentrations

The pollution with lead and zinc in seaweed and blue mussels in Arsuk Fjord has been monitored 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*) over the monitoring period. This assumption was confirmed in a comprehensive study carried out in Godthåbs Fjord (Riget et al. 1997). Geometric mean values were calculated for samples at the same station in the same year.

Analyses of temporal trend of lead concentrations in blue mussels were applied for size groups with a 2 to 4 cm shell length and with 5 to 8 cm shell length separately. Separating blue mussels into two size groups was done because lead concentrations increase with length (age) of the mussels (Riget et al. 1996). This is not the case for zinc, so no separation between size groups was done for zinc. If two samples of blue mussels belonging to same size group were available from the same station in the same year, the geometric mean value was calculated and used in the temporal trend analyses.

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

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

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

The temporal trend analyses also give the overall annual change estimated from the log-linear regression.

3.3.1 Seaweed

The results of the temporal trend analysis in seaweed are shown in Table 1 and Figure 8 and 9.

Table 1. Results of the temporal trend analyses of lead and 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. Only stations with data from 7 or more years were included in the analyses.

Station/Year	Seaweed – lead			Seaweed – zinc		
	Log-linear trend	Non-linear trend	Annual change	Log-linear trend	Non-linear trend	Annual change
1 1982-2010	sign	-	-6.2%	-	-	0.0%
3, 1982-2010	sign	-	-3.8%	-	-	+0.2%
4, 1982-2010	sign	-	-3.6%	-	-	-1.6%
5, 1982-2010	sign	-	-5.2%	sign	-	-3.6%
6, 1982-2010	sign	-	-7.1%	sign	-	-3.4%
8, 1982-2010	sign	sign	-2.5%	sign	-	-2.5%
9, 1982-2010	-	-	-4.3%	-	-	-1.8%
10, 1982-2010	sign	-	-4.1%	-	-	-0.2%
11, 1982-2010	sign	-	-5.9%	-	-	-0.1%

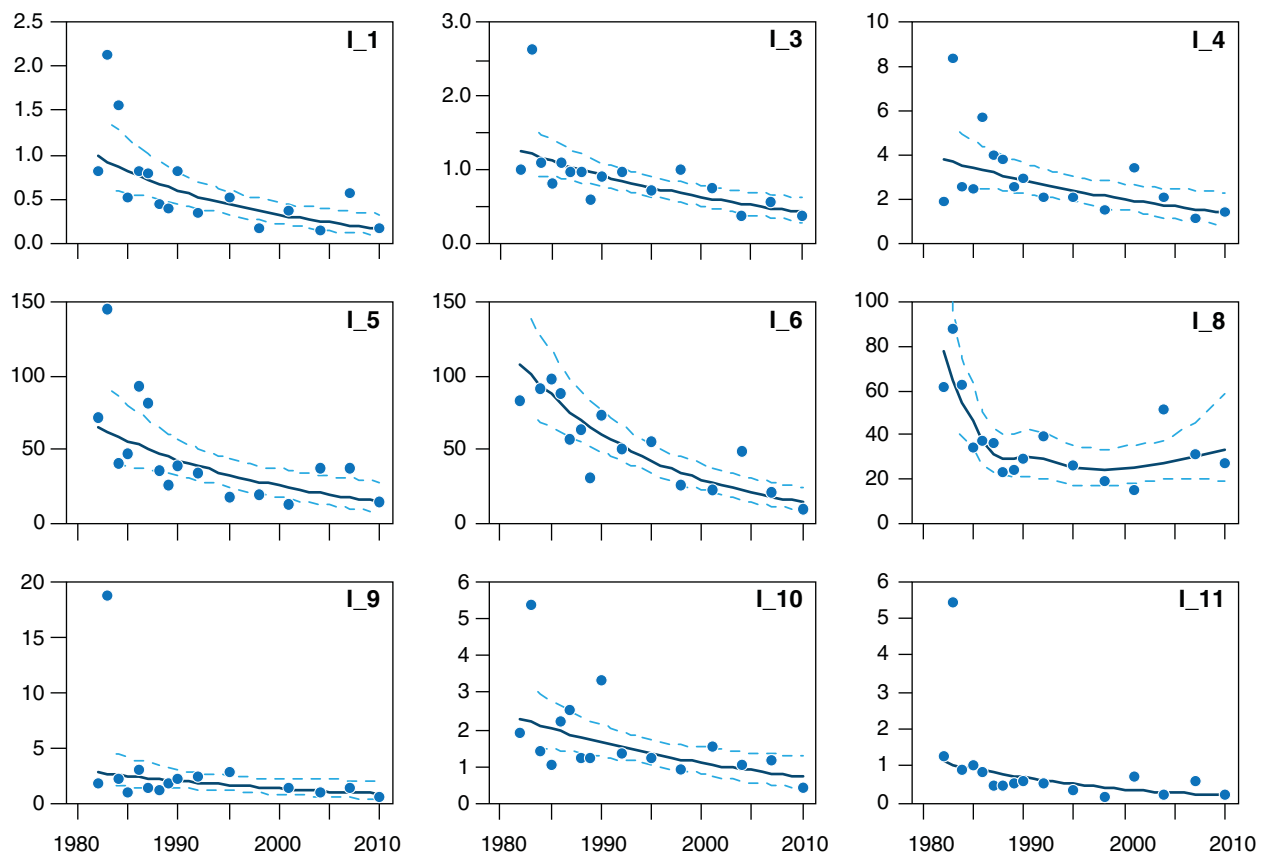


Figure 8. Temporal trends of lead concentrations in seaweed at stations 1-11 from 1982 to 2010. Points denote annual geometric mean concentrations. Solid lines together with 95% confidence broken lines are given when significant trends were found in the temporal trend analysis. A solid line alone is given when no significant trend was found.

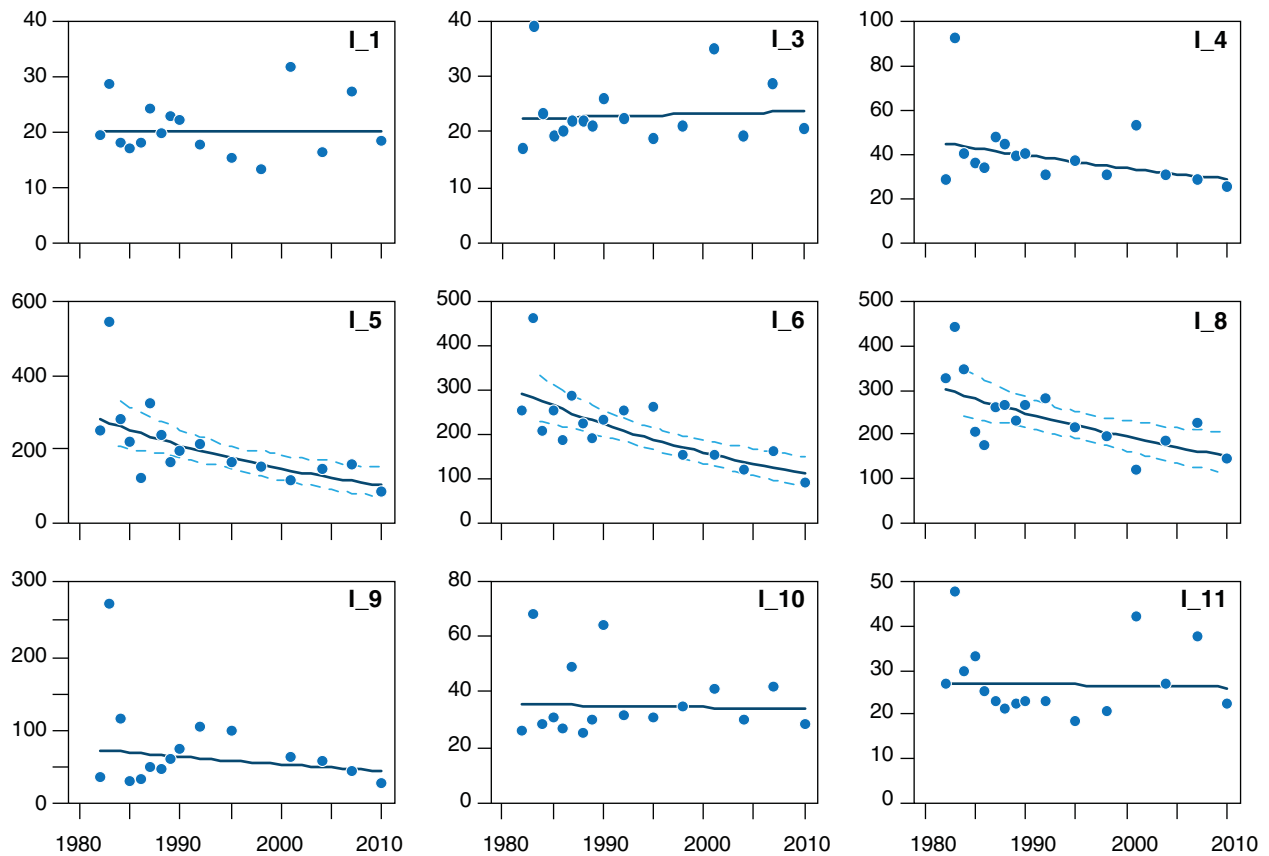


Figure 9. Temporal trend of zinc concentrations in seaweed at stations 1-11 from 1982 to 2010. Points denote annual geometric mean concentrations. Solid line together with 95% confidence broken lines is given when significant trend was found in the temporal trend analysis. Solid line alone is given when no significant trend was found.

There is a decrease ranging from 2.5 to 7.1% per year for the lead concentration in seaweed at all stations in the period 1982 to 2010. For all stations except station 9 the temporal trend was significant at the 5% level. The significant trend could be described as an exponential decrease at all stations, except station 9 which showed no temporal trend and station 8 which showed a non-linear trend (on a log scale). The latter showed a sharp decrease in the beginning of the period followed by a nearly constant level.

No such clear picture is seen for the zinc concentration in seaweed. Levels have decreased significantly at the stations with the highest concentrations (stations 5, 6 and 8 at Ivittuut) and the trend could be described as an exponential decrease. Outside the area at Ivittuut (stations 5, 6 and 8) zinc concentrations in seaweed have not decreased over the monitoring period.

3.3.2 Blue mussels

The results of the temporal trend analysis in blue mussels are shown in Table 2 and Figure 10 (lead), and in Table 3 and Figure 11 (zinc).

Table 2. Results of the temporal trend analyses of lead concentrations in blue mussels of size group 2 to 4 cm and 5 to 8 cm shell length, respectively. 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.

Blue mussel – Pb	Size 2 to 4 cm			Size 5 to 8 cm		
	Log-linear trend	Non-linear trend	Annual change	Log-linear trend	Non-linear trend	Annual change
1, 1982-2010	sign	-	-3.8%	sign	-	-5.5%
3, 1982-2010	-	-	-2.9%	sign	-	-4.6%
4, 1982-2010	sign	sign	-5.7%	sign	sign	-4.8%
5, 1982-2010	sign	-	-5.8%	sign	-	-3.3%
8, 1982-2010	-	-	-0.4%	-	-	-1.8%
10, 1982-2010	sign	-	-2.5%	sign	-	-3.4%
11, 1982-2010	sign	-	-5.8%	sign	-	-5.2%
12, 1983-2010	sign	-	-4.3%	sign	sign	-3.7%
13, 1983-2010	sign	-	-3.3%	sign	-	-3.4%
15, 1983-2010	sign	-	-3.4%	sign	-	-3.5%
16, 1986-2010	sign	-	-4.3%	sign	-	-4.4%
17, 1983-2010	sign	-	-5.1%	sign	-	-5.8%
21, 1983-2010	sign	-	-4.2%	sign	-	-5.2%
22, 1983-2010	sign	-	-3.7%	sign	-	-4.0%
24, 1983-2010	sign	-	-3.3%	sign	-	-4.3%
27, 1984-2010	sign	-	-3.0%	sign	-	-3.9%
28, 1984-2010	sign	-	-2.9%	sign	-	-5.6%

Lead concentrations in blue mussels have decreased in the period 1982 to 2010 at all stations (Table 2 and Figure 10). The annual rate of decrease during the whole period ranges from 0.4 to 5.8%. For size group 2 to 4 cm, the lead concentrations followed a decreasing exponential curve except at station 3 and 8 where no significant temporal trend was found, and station 4 where lead concentrations increased in the first years of the period and then decreased until 2010. For size group 5 to 8 cm, the temporal trends were significant at all stations except at Station 8 where no significant temporal trend was observed. All station with a significant trend followed an exponential decreasing trend line. In average for all stations and both size groups, the lead decreased by 4% annually, which corresponds to a decrease of 62% during the entire monitoring period from 1982 to 2010.

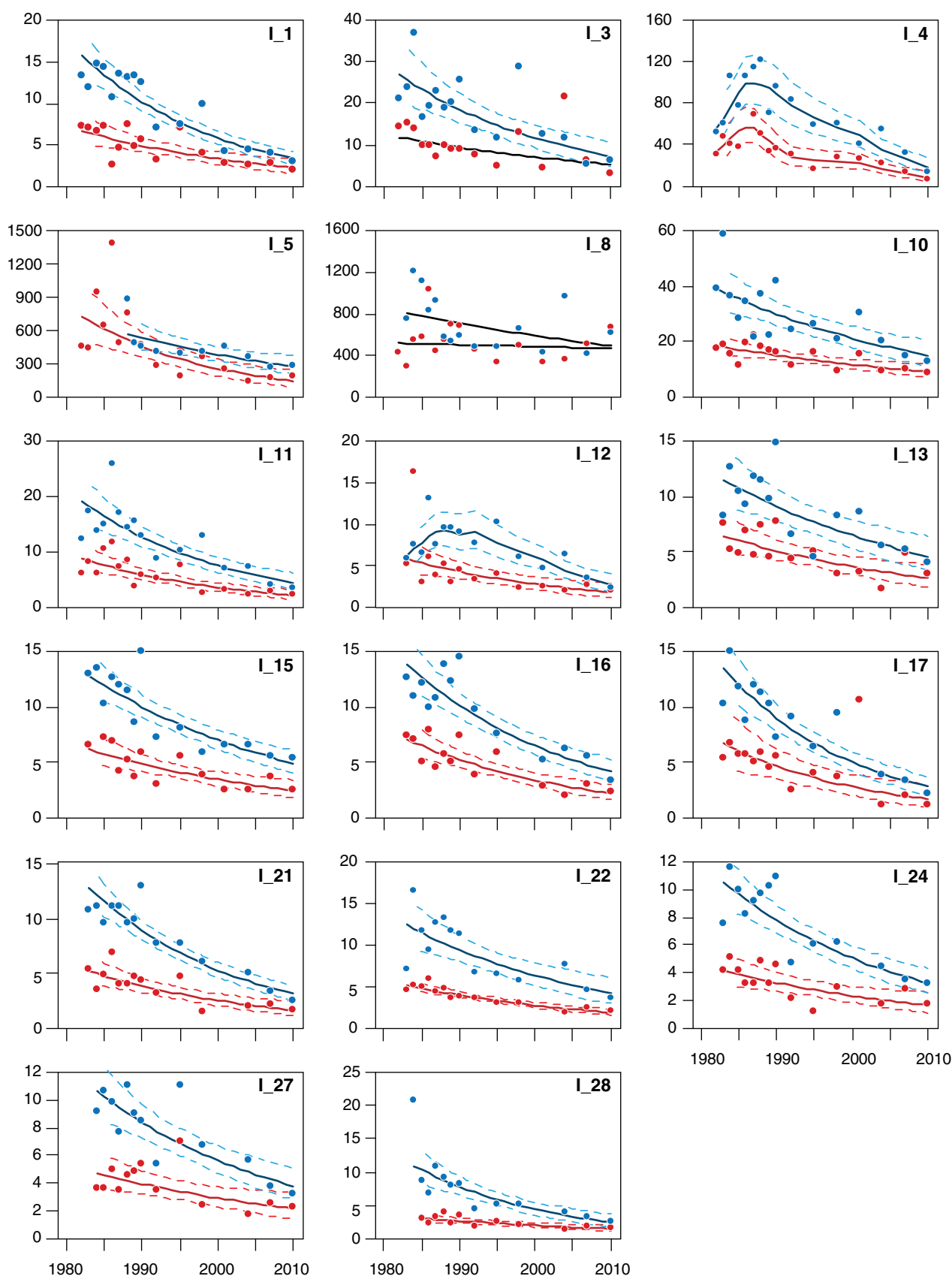


Figure 10. Temporal trend of lead concentrations in blue mussels. Red colours denote results of size group 2 to 4 cm shell length and blue colour denotes results of size group 5 to 8 cm shell length. Points (geometric mean) and solid trend line together with 95% confidence broken lines are given when significant trend was found in the temporal trend analysis. Points and black solid line are given when no significant trend was found.

Table 3. Results of the temporal trend analyses of Zn concentrations in blue mussel. 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.

Blue mussel – Zn			
Station/Year	Log-linear trend	Non-linear trend	Annual change
1, 1982-2010	-	-	-0.7%
3, 1982-2010	sign	-	-1.4%
4, 1982-2010	sign	-	-2.2%
5, 1982-2010	sign	-	-2.6%
8, 1982-2010	sign	sign	-1.1%
10, 1982-2010	sign	-	-1.2%
11, 1982-2010	sign	-	-2.6%
12, 1983-2010	sign	sign	-1.1%
13, 1983-2010	sign	-	-1.4%
15, 1983-2010	-	-	-0.9%
16, 1986-2010	sign	-	-1.0%
17, 1983-2010	-	-	-0.5%
21, 1983-2010	sign	-	-1.9%
22, 1983-2010	-	-	-0.6%
24, 1983-2010	-	-	-1.0%
27, 1984-2010	sign	-	-1.9%
28, 1984-2010	sign	-	-1.2%

Zinc concentrations in blue mussels have also decreased but the rate is lower and the change is significant at only 12 out of 17 stations (Table 3 and Figure 11). At all stations with significant temporal trends, the data followed an exponential decreasing trendline, except at station 8 and 12. It is notable that the zinc concentrations have also decreased at stations where levels are not elevated compared to regions in Greenland with no known local pollution sources. This suggests that the natural zinc levels in blue mussels in Ivittuut are lower compared to mussels from these areas.

In order to illustrate an overall, simplified time trend of lead and zinc concentrations, stations sampled have been divided into three groups according to concentrations levels (and distance to the source) and temporal trend shown in Figure 12-16. For each group the mean concentration was computed.

For seaweed the groups are:

- At the mine: Stations 5, 6 and 8
- 1 km from the mine: Stations 4 and 9
- 2-6 km from the mine: Stations 1, 3, 10 and 11.

For blue mussels the groups are:

- At the mine: Stations 5 and 8
- 1 km from the mine: Stations 4 and 9
- 2-10 km from the mine: Stations 1, 3, 10, 11, 12, 13, 15, 16, 17, 21, 22, 24 and 28.

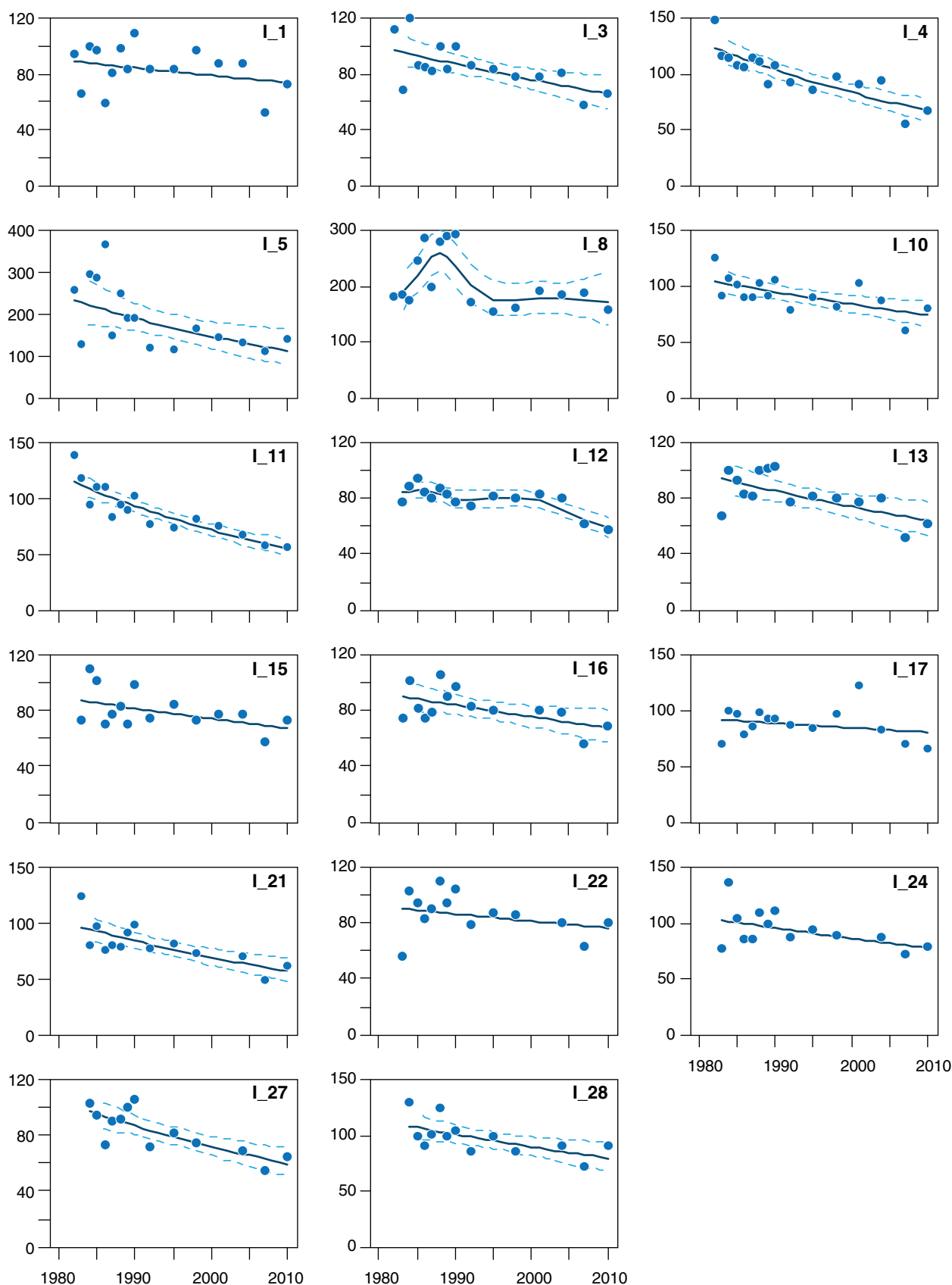


Figure 11. Temporal trend of Zn concentrations in blue mussels. Points denotes annual geometric mean concentration, solid line together with 95% confidence broken lines are given when significant trend was found in the temporal trend analysis. Solid line alone is given when no significant trend was found.

Time trends of lead and zinc concentrations are illustrated in Figure 12-16. Note that the scale in the Figures 12-15 is logarithmic.

Both in seaweed and blue mussels lead concentrations have decreased by about 4% per year since 1982. We expect that this rate of decrease will continue. A similar consistent pattern is not seen for zinc; in most cases there is no significant trend.

Figure 12. Time trend of the lead concentration in seaweed (*Fucus vesiculosus*) in different groups of stations at Ivittuut, 1982-2010.

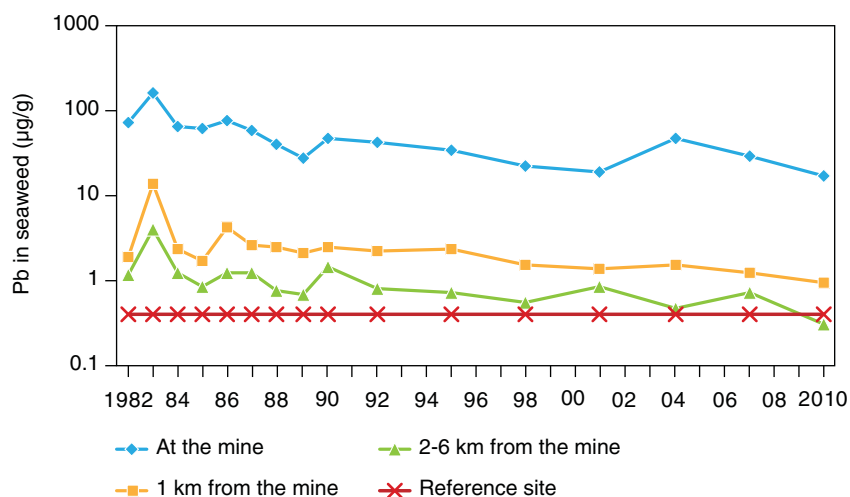


Figure 13. Time trend of the lead concentration in small blue mussels (*Mytilus edulis*) in different groups of stations at Ivittuut, 1982-2010.

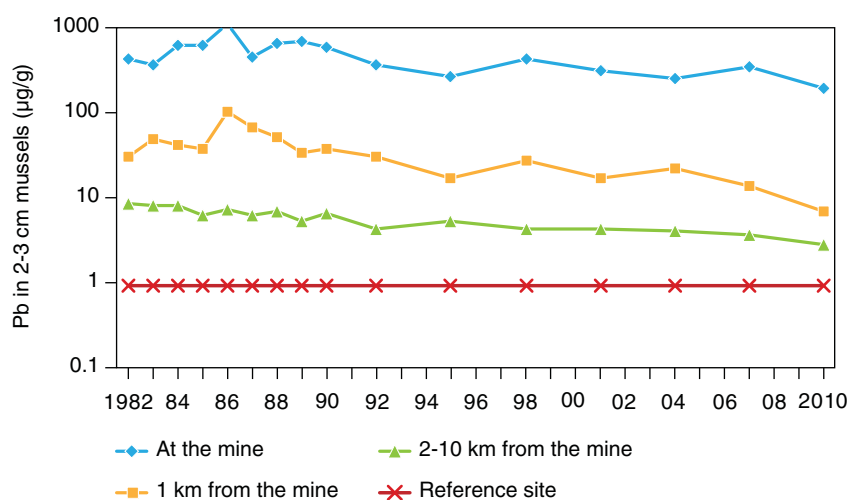


Figure 14. Time trend of the lead concentration in large blue mussels (*Mytilus edulis*) in different groups of stations at Ivittuut 1982-2010.

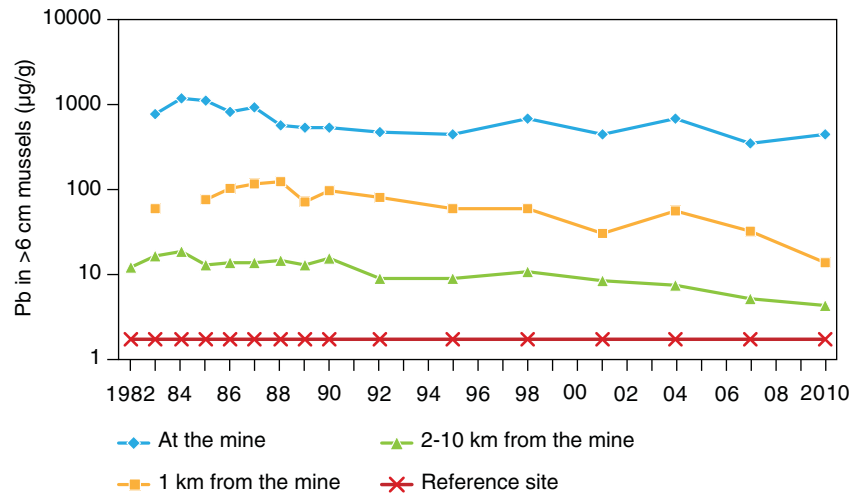


Figure 15. Time trend of the zinc concentration in seaweed (*Fucus vesiculosus*) in different groups of stations at Ivittuut 1982-2010.

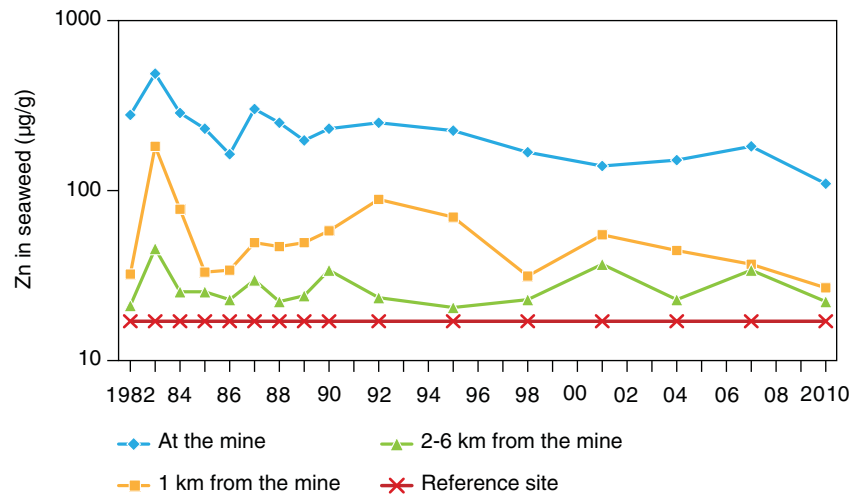
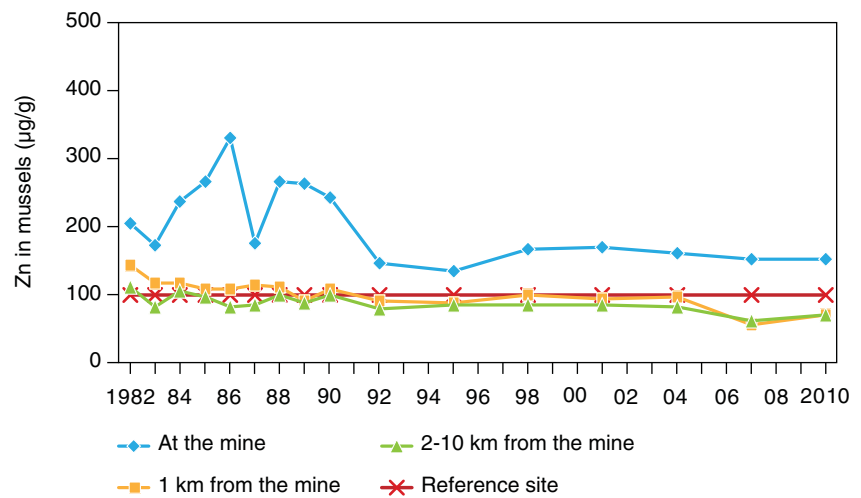


Figure 16. Time trend of the zinc concentration in blue mussels (*Mytilus edulis*) in different groups of stations at Ivittuut 1982-2010.



3.4 Restrictions for eating blue mussels

In Greenland blue mussels may be collected locally and eaten. The elevated lead levels found in Arsuk Fjord implies a risk to human health. This risk has been evaluated by comparing the levels found in the fjord to the “maximum residue level” for lead in Greenlandic diet items. This level is 1.5 µg/g wet weight for mussels (Anon. 2005). As the mean dry weight percentage in the mussels is roughly 16%, the “maximum residue level” equals 9.4 µg/g on a dry weight basis.

This level is exceeded on stations 4, 5, 8 and 10 around Ivittuut (Figure 2) and will also be exceeded at some distance outside the area where these stations occur. In order to fix the area of the coastline where the “maximum residue level” is exceeded, we have extrapolated between the values found at station 4 and 3 south of Ivittuut and between 10 and 11 north of Ivittuut. The result is shown in Figure 17, and on the coastline shown it is recommended not to collect and eat blue mussels. This area is similar to that found in 2007 (Johansen et al. 2008), but smaller than found in 2004 (Johansen & Asmund 2005) and much smaller than found in the period 1982-1992. During this period it also included part of the western coastline of Arsuk Fjord (Johansen et al. 1995).

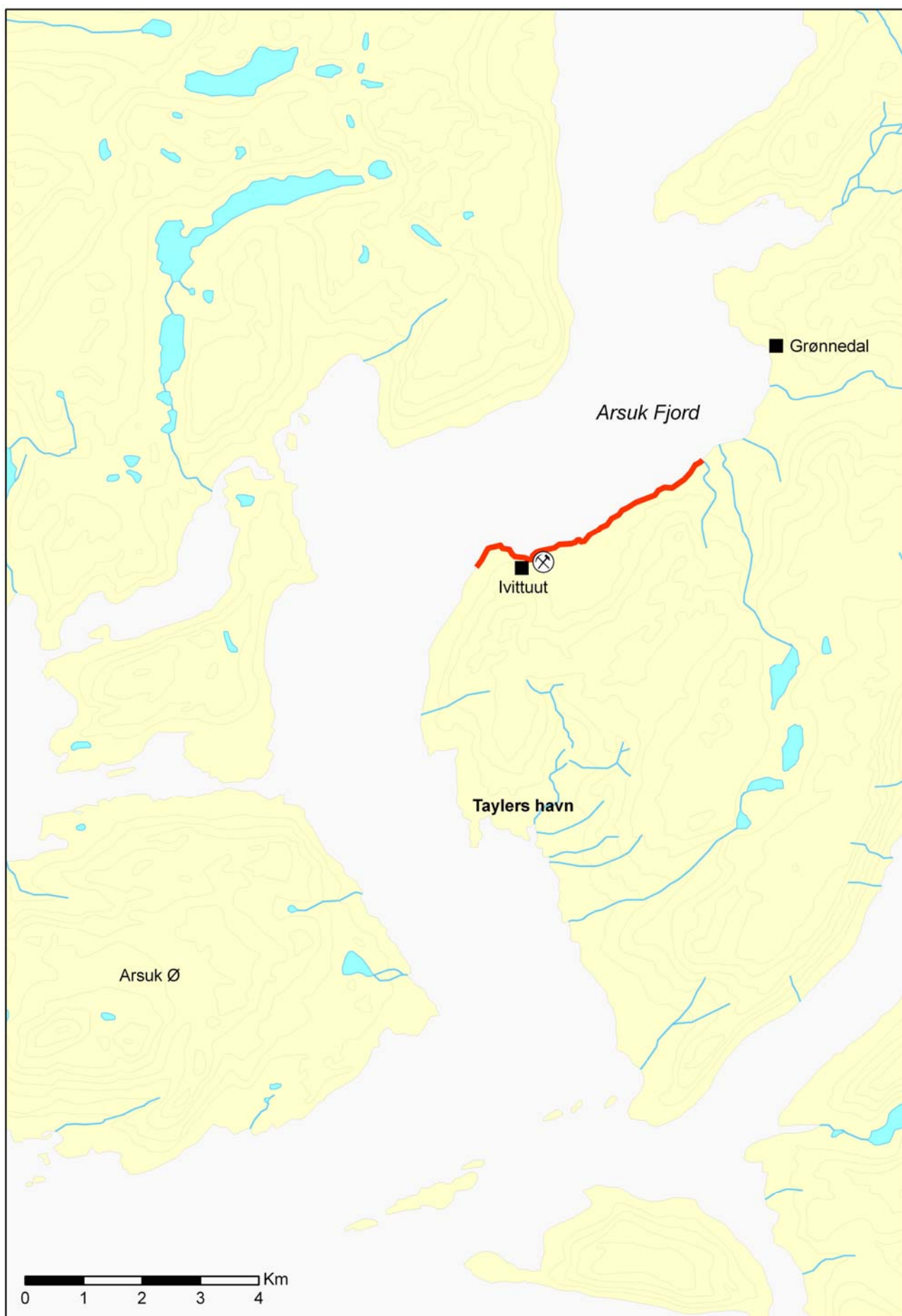


Figure 17. Area where it is recommended not to collect and eat blue mussels.

4 Conclusion

In brown seaweed elevated lead levels were found on a c. 4 km stretch of coastline in eastern Arsuk Fjord around Ivittuut, whereas zinc levels were elevated on most of the coastline studied in Arsuk Fjord. In blue mussels elevated lead levels were seen in all of the studied parts of Arsuk Fjord, and also on coasts 3-4 km outside the fjord. Zinc levels in blue mussels were elevated only at Ivittuut.

Along a stretch of coastline of c. 5 km around Ivittuut the lead concentration in blue mussels is so high that it is recommended not to eat blue mussels from this area. This area is similar to that found in 2007, but smaller than found in 2004 and much smaller than found in the period 1982-1992. During that period it also included part of the western coastline of Arsuk Fjord.

Over the entire monitoring period (1982 to 2010) a decline of lead levels is seen in both brown seaweed and blue mussels in Arsuk Fjord. Lead concentrations have decreased c. 3 times since 1982. Zinc concentrations have also generally decreased, but at a slower rate.

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Annex 1. Brown seaweed data 2010

Zinc and lead concentrations ($\mu\text{g/g d.w.}$) in brown seaweed (*Fucus vesiculosus*)

ID no	Station	Zn	Pb
43837	St. 1	19.54	0.18
43838	St. 1	17.25	0.15
43841	St. 2	21.83	0.20
43842	St. 2	23.82	0.17
43843	St. 3	20.73	0.39
43844	St. 3	20.74	0.37
43849	St. 4	28.23	1.47
43850	St. 4	22.94	1.34
43845	St. 5	91.78	13.08
43846	St. 5	84.81	14.54
43851	St. 6	86.46	9.47
43852	St. 6	98.71	11.47
43871	St. 8	134.86	25.05
43872	St. 8	164.26	29.83
43853	St. 9	27.49	0.56
43854	St. 9	27.52	0.50
43885	St. 10	22.63	0.27
43886	St. 10	33.99	0.70
43886	St. 10	34.91	0.78
43821	St. 11	24.12	0.22
43822	St. 11	20.56	0.23
43803	St. 12	17.01	0.16
43803	St. 12	16.78	0.19
43804	St. 12	21.85	0.35
43807	St. 13	23.20	0.20
43808	St. 13	20.01	0.19
43811	St. 15	19.78	0.35
43812	St. 15	15.98	0.22
43815	St. 16	19.16	0.20
43816	St. 16	18.98	0.21
43861	St. 17	15.66	0.15
43862	St. 17	16.49	0.10
43819	St. 20	14.21	0.15
43820	St. 20	13.76	0.16
43825	St. 21	16.71	0.29
43825	St. 21	15.37	0.41
43826	St. 21	17.21	0.21
43863	St. 22	20.62	0.54
43864	St. 22	19.77	0.16
43865	St. 24	22.25	0.16
43866	St. 24	23.23	0.13
43823	St. 27	19.82	0.37
43824	St. 27	14.21	0.36
43868	St. 28	20.42	0.10
43868	St. 28	20.96	0.09
43867	St. 28	19.08	0.12

Annex 2. Blue mussel data 2010

Zinc and lead concentrations (µg/g d.w.) in blue mussel (*Mytilus edulis*).

ID No	Station	Shell length group	Mean shell length cm	Dry weight %	Number	Mean weight (g)	Zn	Pb
43839	St. 1	2-3 cm	2.45	14.94	40	0.58	78.12	2.10
43840	St. 1	5-6 cm	5.45	14.27	20	2.70	64.75	2.95
43840	St. 1	5-6 cm	5.45	14.27	20	2.70	68.61	3.22
73847	St. 2	2-3 cm	2.45	15.13	40	0.54	91.84	2.96
43848	St. 2	6-7 cm	6.45	15.34	20	8.71	72.53	4.76
43855	St. 3	2-3 cm	2.45	15.86	40	0.59	74.69	2.98
43856	St. 3	6-7 cm	6.41	15.53	20	8.32	57.95	6.45
43857	St. 4	2-3 cm	2.45	16.77	40	0.58	67.81	6.98
43857	St. 4	2-3 cm	2.45	16.77	40	0.58	69.21	6.88
43858	St. 4	6-7 cm	6.42	16.21	20	8.59	66.33	13.43
43859	St. 5	2-3 cm	2.45	15.72	40	0.57	152.04	195.21
43860	St. 5	6-7 cm	6.45	15.42	19	8.45	133.81	288.93
73871	St. 8	2-3 cm	2.45	16.39	40	0.55	197.00	667.97
43872	St. 8	4,7-6,0 cm	5.27	17.10	20	4.22	126.59	622.98
43887	St. 10	2-3 cm	2.75	15.43	40	0.59	85.14	9.01
43888	St. 10	6-7 cm	6.37	13.91	19	7.33	75.29	13.08
43827	St. 11	2-3 cm	2.45	15.18	40	0.52	67.46	2.40
43828	St. 11	5,6-7 cm	6.25	17.86	20	8.17	46.52	3.49
43801	St. 12	2-3 cm	2.45	18.44	40	0.55	59.80	2.04
43802	St. 12	6-7 cm	6.41	16.47	20	8.60	55.78	2.37
43805	St. 13	2-3 cm	2.45	16.63	40	0.51	60.99	2.84
43805	St. 13	2-3 cm	2.45	16.63	40	0.51	59.16	3.09
43806	St. 13	6-7 cm	6.45	15.18	20	8.13	63.46	3.98
43809	St. 15	2-3 cm	2.45	16.55	40	0.49	80.15	2.59
43810	St. 15	6-7 cm	6.45	15.09	18	7.92	65.38	5.45
43813	St. 16	2-3 cm	2.45	16.15	40	0.54	70.67	2.35
43814	St. 16	5,6-6,8 cm	6.12	16.73	20	7.12	67.60	3.33
43875	St. 17	2-3 cm	2.45	15.71	40	0.48	74.27	1.10
43876	St. 17	6-7 cm	6.40	16.71	20	6.85	59.67	2.13
43829	St. 19	2-3 cm	2.45	17.93	40	0.48	66.26	1.56
43830	St. 19	6-7 cm	6.41	15.60	40	7.71	58.34	2.19
43817	St. 20	2-3 cm	2.45	15.06	40	0.43	77.29	1.47
43818	St. 20	5,6-7 cm	6.09	15.13	20	6.90	69.73	2.29
43831	St. 21	2-3 cm	2.45	16.75	40	0.45	68.20	1.74
43832	St. 21	6-7 cm	6.44	15.75	18	7.85	57.11	2.59
43877	St. 22	2-3 cm	2.45	15.45	40	0.50	89.90	2.14
43878	St. 22	6-7 cm	6.45	16.46	20	8.01	70.55	3.60
43879	St. 24	2-3 cm	2.45	16.37	40	0.56	79.88	1.81
43880	St. 24	5,6-7 cm	6.25	15.42	20	7.39	79.40	3.23
43833	St. 26	2-3 cm	2.45	17.64	40	0.61	65.67	1.32
43833	St. 26	2-3 cm	2.45	17.64	40	0.61	66.31	1.39
43834	St. 26	6-7 cm	6.45	17.32	20	8.55	58.29	1.89
43835	St. 27	2-3 cm	2.60	15.32	40	0.79	74.37	2.25
43836	St. 27	6-7 cm	6.45	17.47	20	7.98	57.20	3.19
43881	St. 28	2-3 cm	2.45	14.68	40	0.51	85.48	1.67
43882	St. 28	6-7 cm	6.45	12.58	20	7.34	95.29	2.51
43883	St. 29	2-3 cm	2.45	12.95	40	0.50	98.69	1.32
43884	St. 29	5,2-6,7 cm	5.81	12.76	20	5.72	80.99	2.32

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A background photograph of a coastal town in South Greenland. In the foreground, a calm body of water reflects the sky. A prominent red building with several windows stands on a slight elevation. To its left, a smaller building with a large arched opening is visible. In the background, steep, rocky mountains rise, some with patches of snow. The sky is a clear, pale blue.

ENVIRONMENTAL MONITORING AT THE CRYOLITE MINE IN IVITTUUT, SOUTH GREENLAND, IN 2010

This report evaluates the pollution in Arsuk Fjord at Ivittuut in South Greenland based on environmental studies conducted in 2010. The area is polluted by lead and zinc caused by the mining of cryolite that took place from 1854 to 1987. The 2010 study shows that the lead pollution of the fjord continues to fall. Zinc concentrations also generally decrease, but slower. We have found elevated lead concentrations in blue mussels in outer Arsuk Fjord and in areas 3-4 km outside the fjord. On a c. 5 km stretch of coastline around Ivittuut, the lead concentration in blue mussels is so high, that it is recommended not to collect and eat mussels. Lead and zinc concentrations in brown seaweed are also elevated in parts of Arsuk Fjord.