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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 2007. The area is polluted by lead and zinc caused by the mining of cryolite that took place from 1854 to 1987. The 2007 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 collecting and eating mussels from this area. Lead and zinc concentrations in brown seaweed are also elevated in a large part of Arsuk Fjord.

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

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Cover photo: The cryolite mine in Ivittuut, while mining still took place (photo: Kryolitselskabet Øresund A/S)

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Contents

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 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 shrimp 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 2007.

The geographical pattern of lead and zinc levels found in brown seaweed and blue mussels in 2007 shows that waste rock in Ivittuut still is the main source of the pollution of the fjord.

In brown seaweed elevated lead levels were found on a c. 20 km stretch of coastline in eastern Arsuk Fjord around Ivittuut, whereas zinc levels were elevated on the entire 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.

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 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 2007) a decline of lead levels is seen in both brown seaweed and blue mussels in Arsuk Fjord. In average lead concentrations have decreased by a factor of 2.5 since 1982. Zinc concentrations also generally have decreased, but at a slower rate.

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 zinkmineraler, 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 2007.

Den geografiske fordeling af bly- og zinkkoncentrationen i blæretang og blåmusling i 2007 viser, at kajområdet ved Ivittuut fortsat er den dominerende forureningskilde.

I blæretang er der forhøjede blyværdier på en ca. 20 km lang kyststrækning i den østlige del af Arsuk Fjord omkring Ivittuut, mens der er forhøjede zinkværdier på hele kyststrækningen af det undersøgte område. I blåmuslinger er der forhøjede blyværdier i alle undersøgte områder af Arsuk Fjord, men også i områder 3-4 km udenfor fjorden.

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 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 2007) er blykoncentrationen i både blæretang og blåmusling faldet i Arsuk Fjord. Blykoncentrationerne er nu i gennemsnit to en halv gang lavere end de var i 1982. Zinkkoncentrationen i tang og musling er også faldet, men ikke så meget som blykoncentrationen.

Eqikkaaneq

Arsuup iluatungaani Ilorput-mi Ivittuut 1854-imiit 1987-mut orsugiammik piiaaffiusimavoq, immikkoortiteriffiulluni aallarussuiffiullunilu. Orsugiassiorneq pissutigalugu kangerluk aqerlumik zinkimillu mingutsitaavoq. Mingutsitsinerup aallaavigineruai ujaqqat immikkoortitikkat orsugiammik piiaaffimmeersut. Immikkoortiternerlukut taakku Ivittuut sissaa atuarlugu qimagarneqarsimapput. Aqerlumik zinkimillu akoqarput ulittarneranillu immamut arrortinneqarlutik Ilutsinnut siammarsimallutik.

Mingutsitsineq 1982-imiilli misissuiffigineqartalerpoq. Misissuisarnerni taakkunani 1985-imiit taamaallaat qeqqussat uillullu misissuiffigineqartalersimapput paasineqareersimammat kangerluup aalisagai raajaalu aqerlumik zinkimillu mingutsitaalluarneq ajortut. Nalunaarusiammi matumani misissuineq kingulleq juli 2007-imi pisoq oqaluttuarineqarpoq.

Aqerlup zinkillu qeqqussani uillunilu ittup 2007-imi siammarsimanera aallaavigalugu takuneqarsinnaavoq Ivittuut umiarsualiviata eqqaa mingutsitsinerup aallaaviginerpaagaa.

Qeqqussat Ivittuut eqqaanni Ilutta kangia-tungaani 20 km ungasissusilik tikillugu aqerlortaqarnerupput, taavalu sinerissami misissuiffiusumi tamarmi annerusumik zinkitaqarlutik. Uillut Ilutsinni misissuiffiusumi tamarmi aqerlortaqarnerupput, aammali kangerluup silataani 3-4 kminik ungasissusilimmi aqerlortaat annertuseqqalluni.

Ivittuut eqqaanni sinerissami 5 km-iterisut isorartussusilimmi uillut ima aqerlortaqartigipput nerineqarnissaat inassutigineqarani. Tamaani paasisat 2004-imi misissukkaniit annikinnerupput aammalu 1982-1992-imi misissuisarnerniit annikinneroqalutik. Piffissami tassanissaaq Ilutta kitaata tungaani sineriak ilanngullugu misissuiffigineqarpoq.

Piffissaq misissuiffiusoq tamaat (1982-2007) isigigaanni Ilutsinni qeqqussat uillullu aqerlortaat annikkilliartorsimavoq. Maanna aqerloq 1982-imiit 2 ½-eriaamik annikinneruvoq. Qeqqussat uillullu annikinnerusumik zinkertaqalersimapput, aqerlulli appariarsimaneratut appariarsimatiginatik.

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 located close to the shore of Arsuk Fjord (Figure 1). The closest settlements are Arsuk, c. 15 km W of Ivittuut, and the Naval Station Grønnedal, c. 5 km NE 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 flotation 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. The most important source has been waste rock, which has been disposed at the coastline in Ivittuut. The waste rock contains lead and zinc, which is released as dissolved metals to Arsuk Fjord, when the tide moves in and out 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).

From 1982 to 1992 environmental monitoring was conducted each year, after which it was carried out in 1995 and each third year since. The results from 1982 to 1992 are summarized in Johansen et al. (1995). Results from 1995 are reported by Riget et al. (1995a), from 1998 by Johansen et al. (1998), from 2001 by Johansen & Asmund (2003) and from 2004 by Johansen & Asmund (2005). The first studies showed that the species affected by the heavy metal pollution were brown seaweed (*Fucus vesiculosus*) and blue mussel (*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 mussel. These two species are widely used to monitor heavy metal pollution. They 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 2007. We compare levels of lead and zinc within the study area and over time and also with lead and zinc levels found in these species in Greenland regions not affected by known local sources.

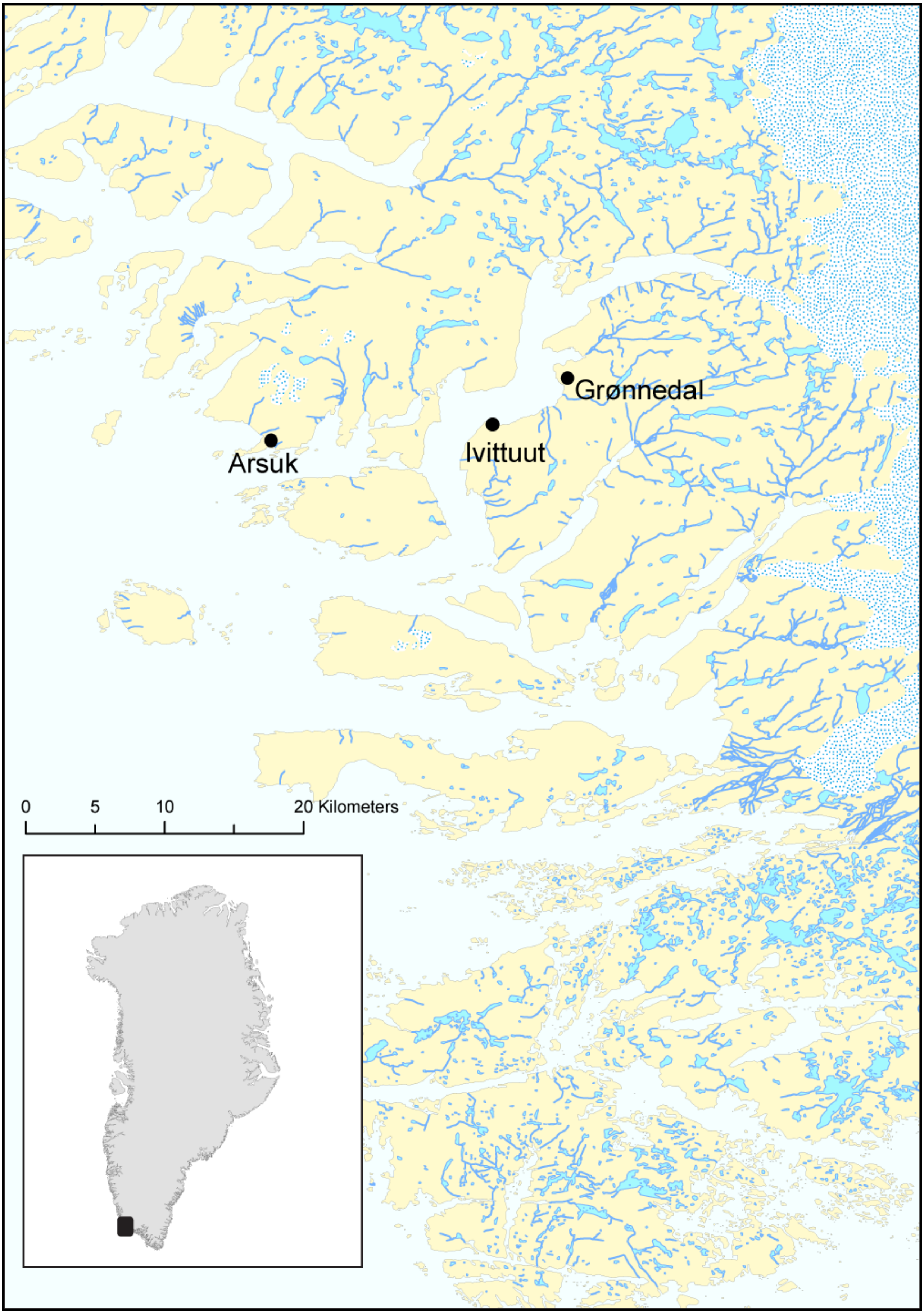


Figure 1. Location of Ivittuut and nearby settlements.

2 Sampling and analyses

Sampling of brown seaweed and blue mussels was conducted in the period 27th June to 4th July 2007 by Sigga Joensen and Lene Bruun from NERI. The study used a boat chartered by the Naval Station Grønnedal, and here the preparation of samples was carried out. Figure 2 shows sampling stations in 2007. They were identical to stations sampled in 2004.

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 Multiwawe 3000 Microwave Oven. Zinc concentrations were determined using flame AAS (Perkin Elmer AAnalyst 300) and lead concentrations were determined using graphite furnace AAS (Perkin Elmer AAnalyst 800).

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 by participating 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.

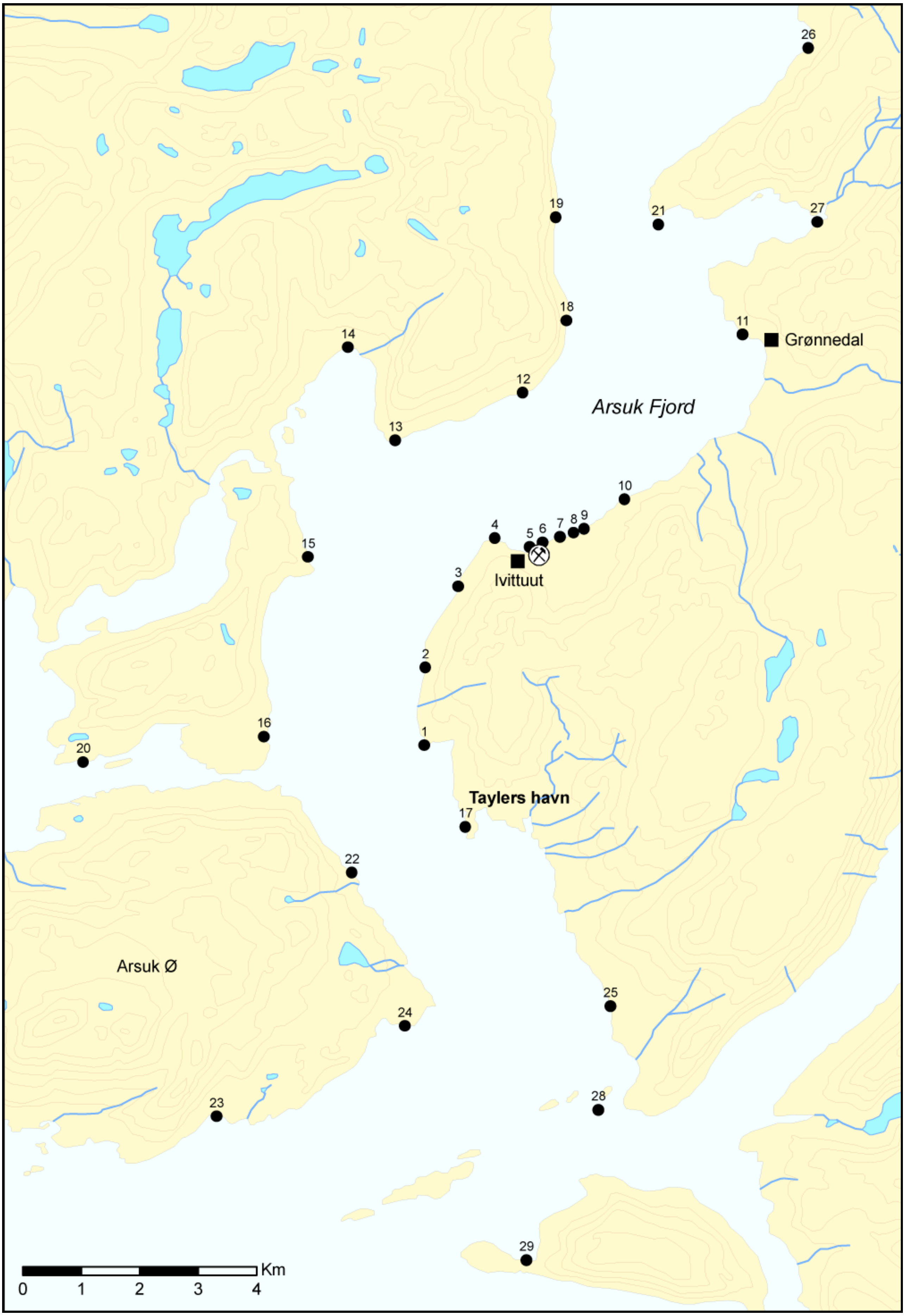
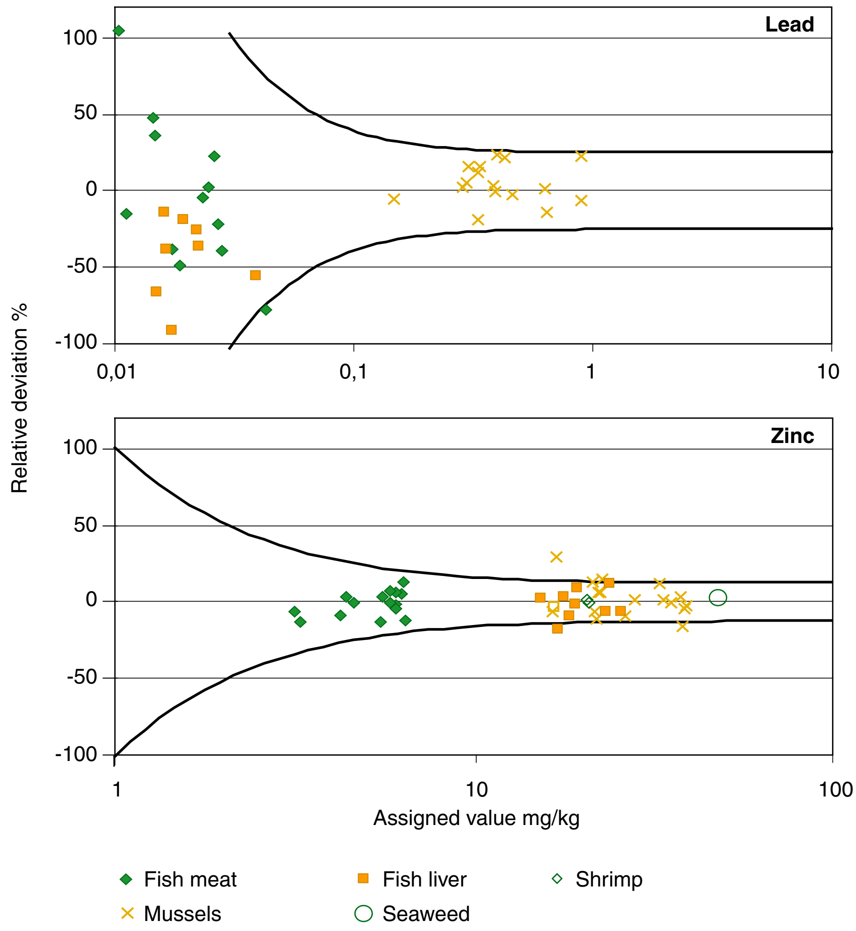


Figure 2. Sampling stations.

Figur 3. Results for lead (above) and zinc (below) from NERI-DAE's participitation 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.



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).

Finally the analytical methods were checked by regularly analyzing the same sample twice (same ID# but different nitric acid digestions). In this study, 9 samples were analyzed twice (Annex 1 and 2). The relative deviation was 4.4% for lead and 1.1% 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 2007 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 year to year, we have sampled and analyzed certain size groups: small mussels with a shell length of 2-3 cm and a larger size group, 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

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. Locally elevated lead and zinc concentrations in seaweed have been found earlier in one area with known mineralization, viz. at Taylers Havn south of Ivittuut, where lead and zinc concentrations in seaweed in the study conducted in 2004 were higher than expected (Johansen et al. 2005).

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, lead levels are elevated in most of the study area, viz. in Arsuk Fjord along the eastern and western coasts to about 10 km both south and north of Ivittuut (Figure 4). In most of this area lead levels are elevated by a factor of about 1.5 to 2. At Ivittuut levels are elevated about 100 times. The pattern for zinc levels in seaweed is similar to that of lead, except that the area affected is larger and zinc levels are elevated in the whole study area (a factor 1.5 to 2) (Figure 5).

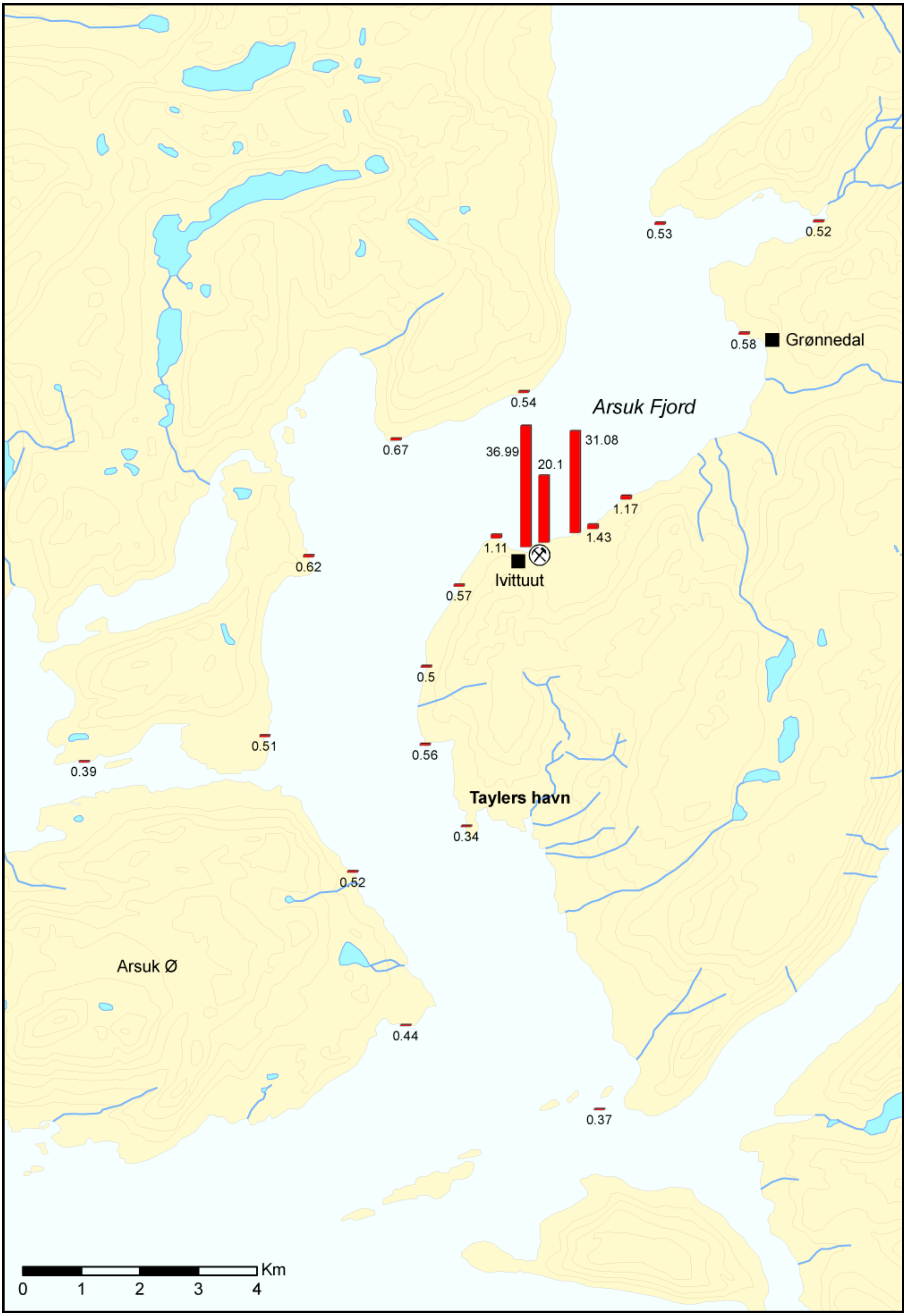


Figure 4. Lead concentration (µg/g dry weight) in brown seaweed (*Fucus vesiculosus*) at Ivittuut 2007.

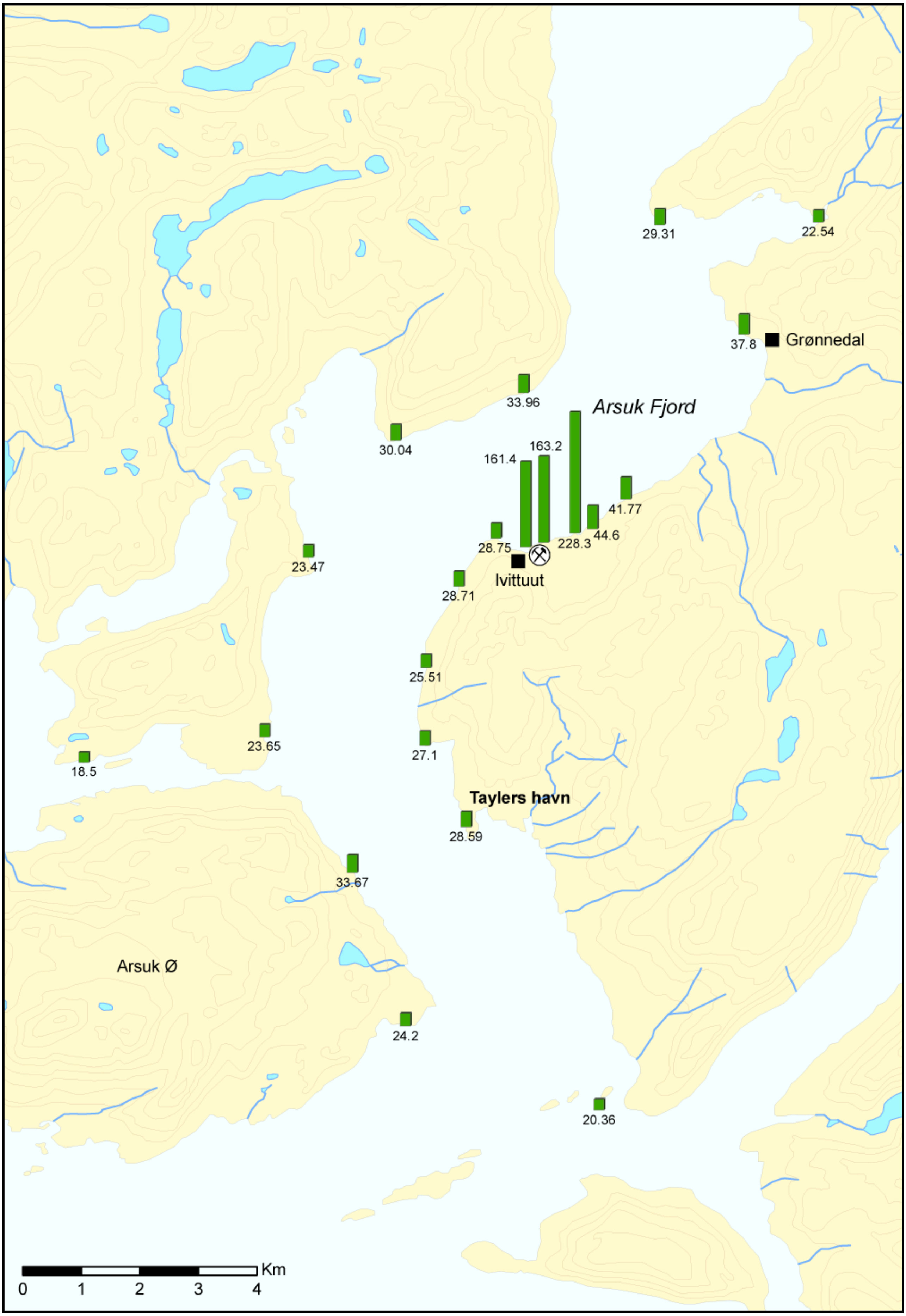


Figure 5. Zinc concentration (µg/g dry weight) in brown seaweed (*Fucus vesiculosus*) at Ivittuut 2007.

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 sources we have found lead and zinc concentration as shown below (Riget et al. 1993, Aar-krog 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 these 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 200-500 times.

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 group 2 to 4 cm shell length and 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.

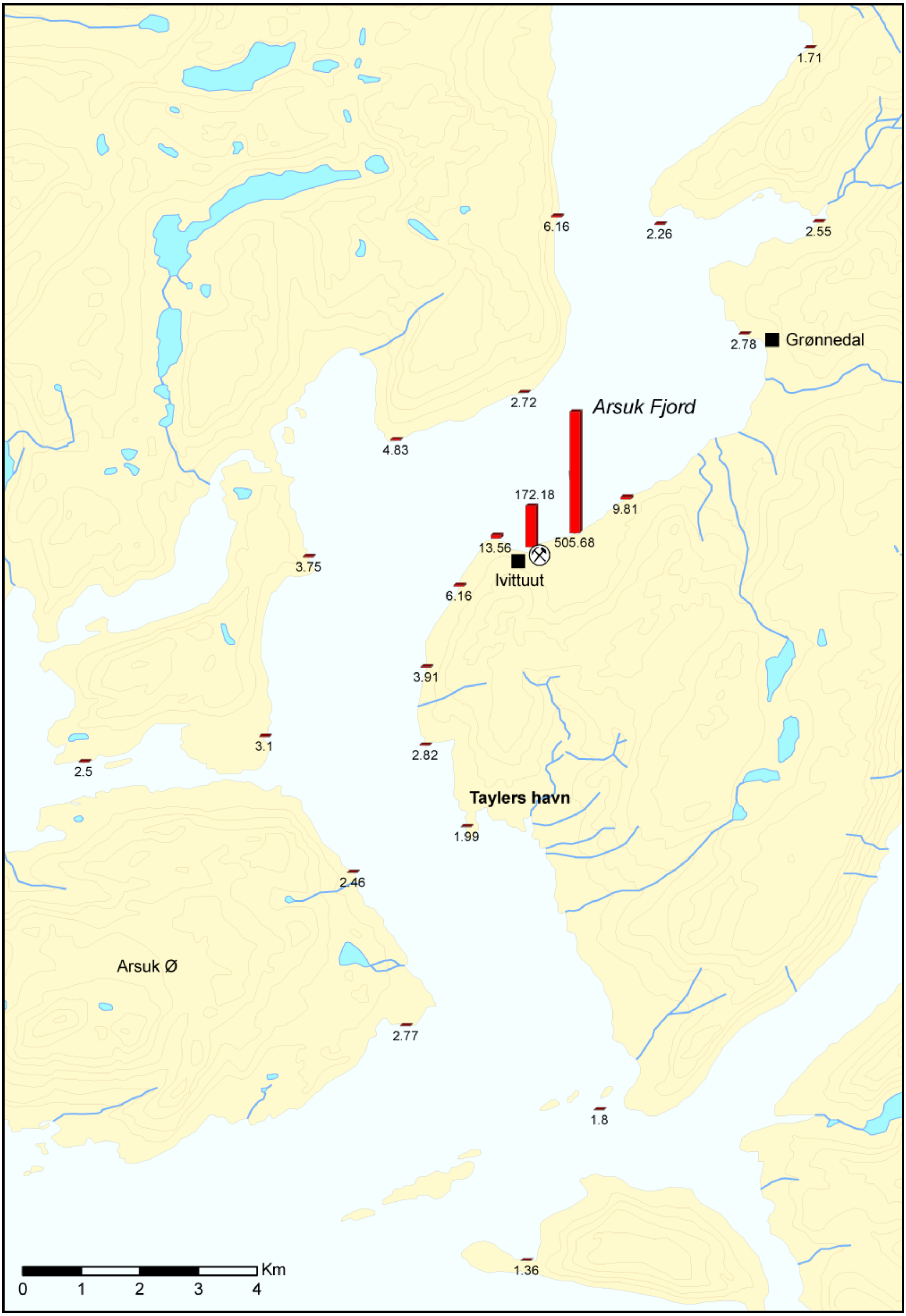


Figure 6. Lead concentration (µg/g dry weight) in small blue mussels (*Mytilus edulis*) at Ivittuut 2007.

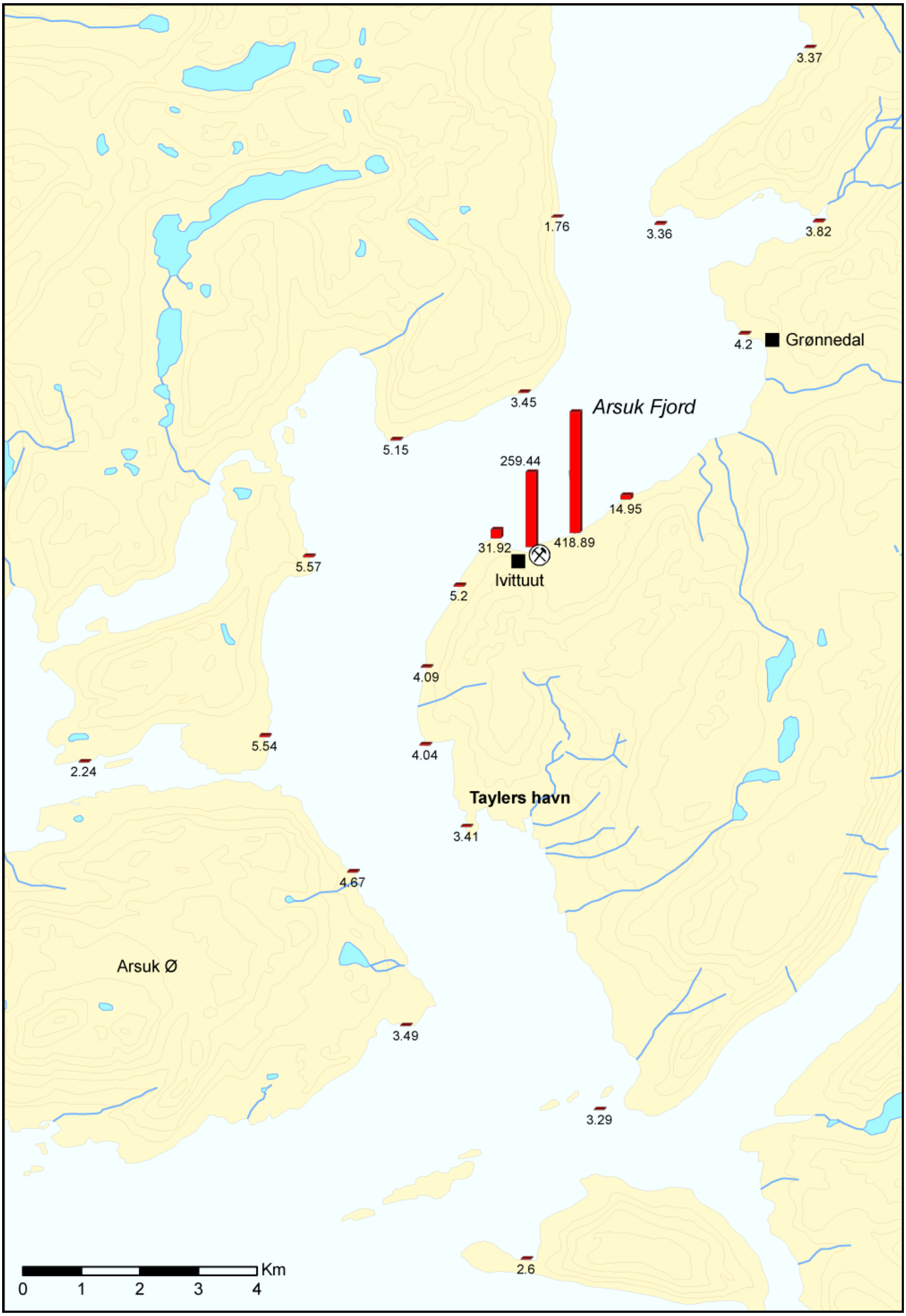


Figure 7. Lead concentration (µg/g dry weight) in large blue mussels (*Mytilus edulis*) at Ivittuut 2007.

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

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

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

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

The results of the temporal trend analysis in seaweed are shown in Table 1 and Figure 8 and 9, and the results for blue mussels in Table 2, Table 3, Figure 10 and Figure 11.

Table 1. Results of the temporal trend analyses of Pb and Zn 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.

	Seaweed – Pb			Seaweed – Zn		
Station/Year	**Log-linear trend**	**Non-linear trend**	**Annual change**	**Log-linear trend**	**Non-linear trend**	**Annual change**
I_1 1982-2007	sign	-	-6.1%	-	-	+0.2%
I_3, 1982-2007	sign	-	-3.6%	-	-	+0.5%
I_4, 1982-2007	sign	-	-3.6%	-	-	-1.3%
I_5, 1982-2007	sign	-	-5.0%	sign	-	-3.2%
I_8, 1982-2007	sign	sign	-2.9%	sign	-	-2.5%
I_10, 1982-2007	-	-	-3.1%	-	-	+0.2%
I_11, 1982-2007	sign	-	-5.9%	-	sign	+0.2%

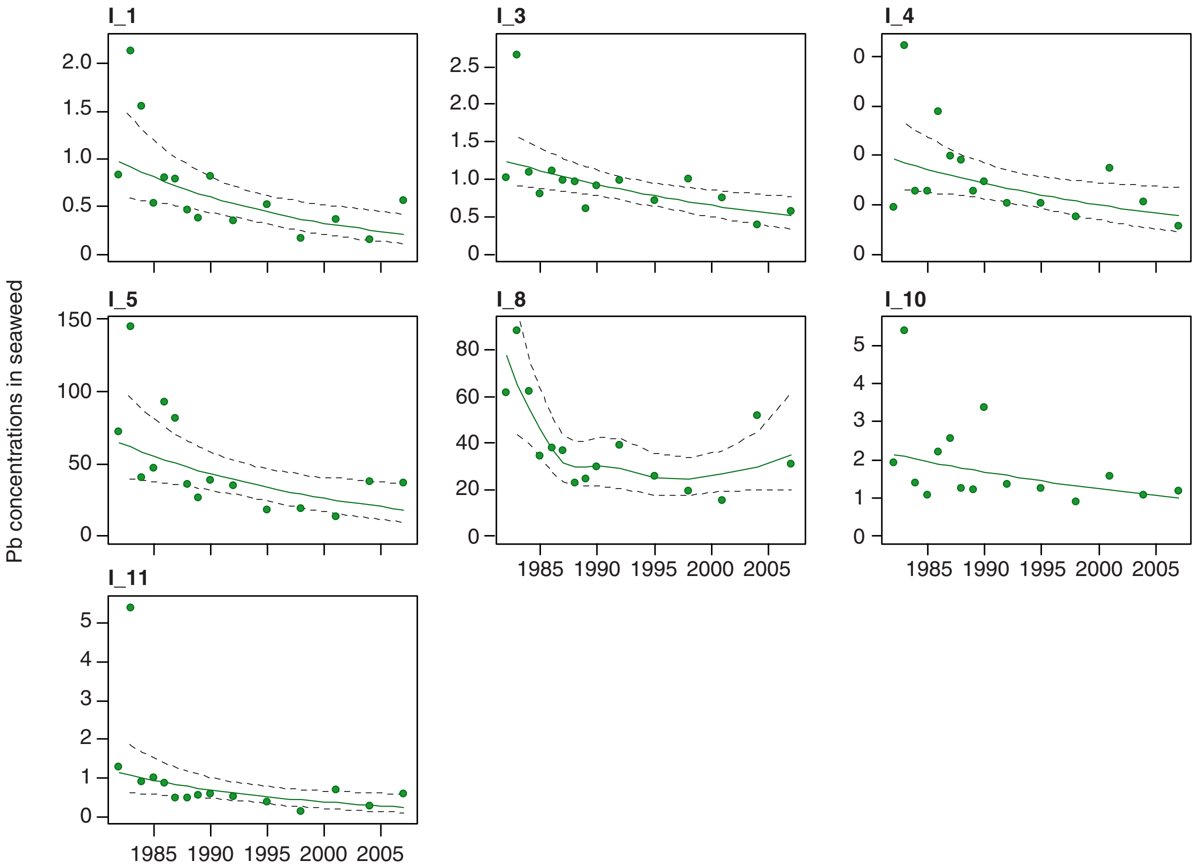


Figure 8. Temporal trend of Pb concentrations in seaweed. Points denote annual geometric mean concentrations. Solid line together with 95% confidence broken lines is given when significant trend was found in the temporal trend analysis. Solid line alone is given when no significant trend was found.

There is a decrease ranging from 2.9 to 6.1% per year for the lead concentration in seaweed at all stations in the period 1982 to 2007. For all stations except station 10 the temporal trend was significant at the 5% level. The significant trend could be described as an exponential decrease at station 1, 3, 4, 5 and 11, whereas the decrease at station 8 was non-linear (on a log scale) with 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 and 8 at Ivittuut) and the trend could be described as an exponential decrease. At station 10 the temporal trend was also statistical significant with a U-shaped trend, but outside the area at Ivittuut (stations 5 and 8) zinc concentrations in seaweed have not decreased over the whole monitoring period.

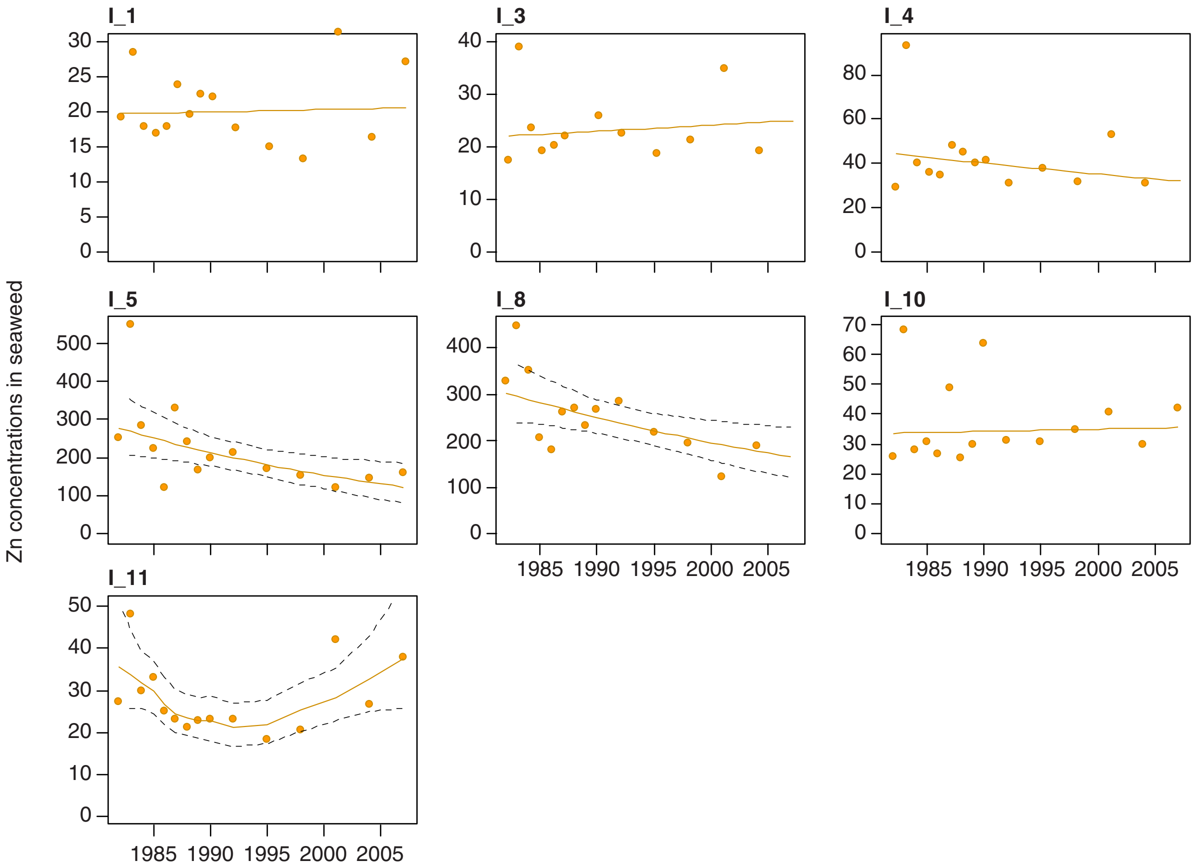


Figure 9. Temporal trend of Zn concentrations in seaweed. Points denote annual geometric mean concentrations. Solid line together with 95% confidence broken lines is given when significant trend was found in the temporal trend analysis. Solid line alone is given when no significant trend was found.

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**		
Station/Year	**Log-linear trend**	**Non-linear trend**	**Annual change**	**Log-linear trend**	**Non-linear trend**	**Annual change**
I_1 1982-2007	sign	-	-3.7%	sign	-	-5.4%
I_3, 1982-2007	-	-	-1.6%	sign	-	-4.4%
I_4, 1982-2007	sign	-	-4.7%	sign	sign	-3.2%
I_5, 1982-2007	sign	-	-6.4%	sign	-	-3.5%
I_8, 1982-2007	-	-	-1.1%	sign	-	-2.3%
I_10, 1982-2007	sign	-	-2.4%	sign	-	-3.1%
I_11, 1982-2007	sign	-	-5.3%	sign	-	-4.6%
I_12, 1983-2007	sign	-	-4.6%	sign	-	-2.6%
I_13, 1983-2007	sign	-	-3.6%	sign	-	-3.0%
I_15, 1983-2007	sign	-	-3.5%	sign	-	-3.8%
I_16, 1986-2007	sign	-	-4.5%	sign	sign	-3.9%
I_17, 1983-2007	sign	-	-4.4%	sign	-	-5.1%
I_21, 1983-2007	sign	-	-4.3%	sign	-	-4.7%
I_22, 1983-2007	sign	-	-4.0%	sign	-	-3.5%
I_24, 1983-2007	sign	-	-3.5%	sign	-	-4.3%
I_27, 1984-2007	sign	-	-3.1%	sign	-	-3.4%
I_28, 1984-2007	sign	-	-3.2%	sign	-	-5.6%

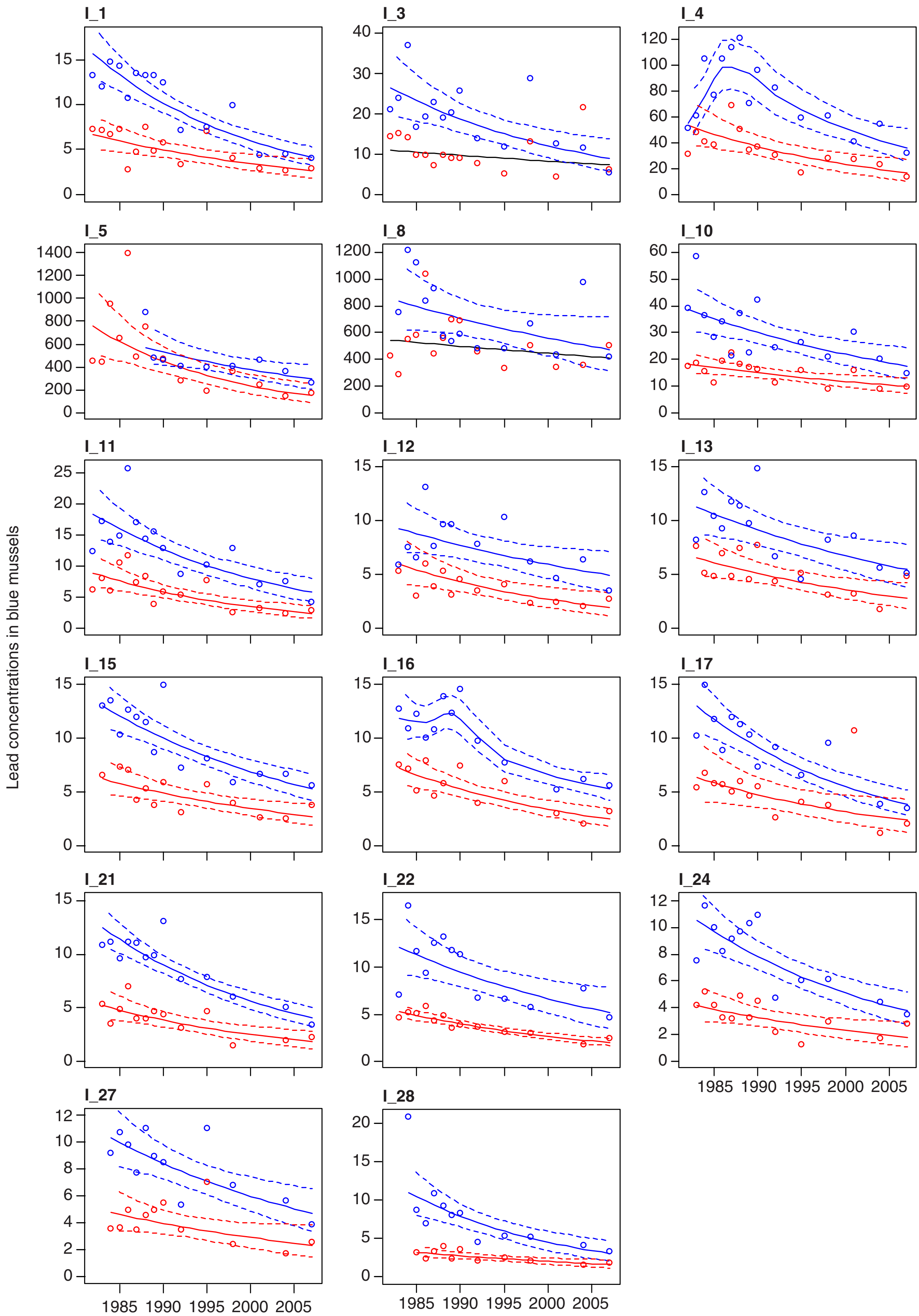


Figure10. Temporal trend of lead concentrations in blue mussels. Red colours denote results of size group 2 to 4 cm shell length and blue colour denotes results of size group 5 to 8 cm shell length. Points (geometric mean) and solid trend line together with 95% confidence broken lines are given when 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**
I_1 1982-2007	-	-	-0.6%
I_3, 1982-2007	sign	-	-1.4%
I_4, 1982-2007	sign	-	-2.2%
I_5, 1982-2007	sign	-	-3.1%
I_8, 1982-2007	-	sign	-0.9%
I_10, 1982-2007	sign	-	-1.4%
I_11, 1982-2007	sign	-	-2.6%
I_12, 1983-2007	sign	-	-0.8%
I_13, 1983-2007	sign	-	-1.3%
I_15, 1983-2007	-	-	-1.1%
I_16, 1986-2007	-	-	-1.1%
I_17, 1983-2007	-	-	0%
I_21, 1983-2007	sign	-	-2.2%
I_22, 1983-2007	-	-	-0.7%
I_24, 1983-2007	-	-	-1.0%
I_27, 1984-2007	sign	-	-2.1%
I_28, 1984-2007	sign	-	-1.5%

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). 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.

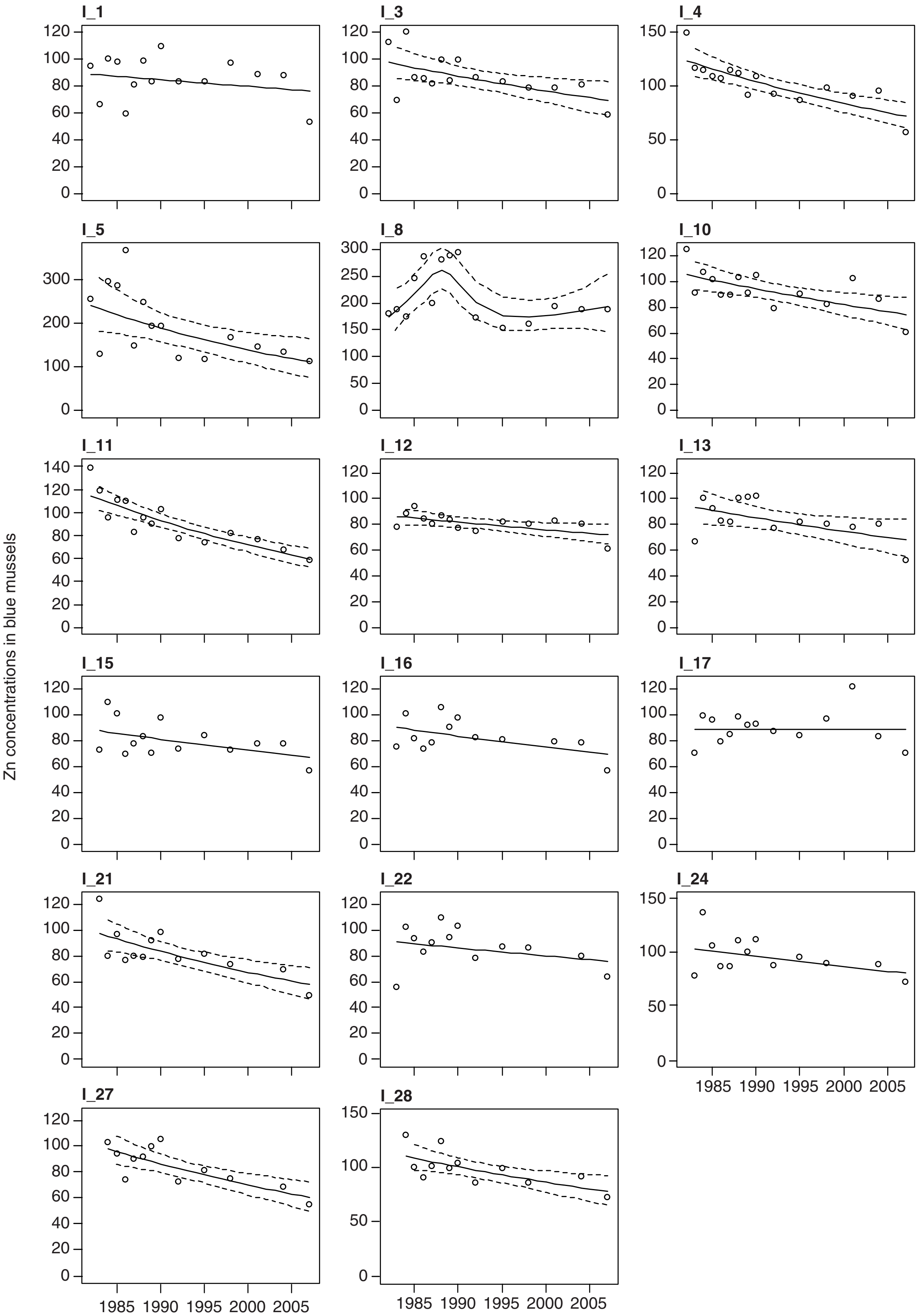


Figure 11. Temporal trend of Zn concentrations in blue mussels. Points denotes annual geometric mean concentration, solid line together with 95% confidence broken lines are given when significant trend was found in the temporal trend analysis. Solid line alone is given when no significant trend was found.

Lead concentrations in blue mussels have decreased in the period 1982 to 2007 at all stations. The annual rate of decrease during the whole period ranges from 1.1 to 6.4%. For size 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. For size 5 to 8 cm, all temporal trends were significant and following an exponential decrease except at station 4 and 16, where lead concentrations increased or were constant in the first years of the period and then decreased until today. In average for all stations and both size groups the lead has yearly decreased 3.83% which correspond to a factor 2.56 over the 25 years of monitoring.

Zinc concentrations in blue mussels have also decreased but the rate is lower and the change is significant at only 10 out of 17 stations. At all stations with significantly temporal trends, this followed an exponential decrease, except at station 8 where the zinc concentrations peaked in the late 1980s. It is notable that zinc concentrations have also decreased at stations where levels are not elevated compared to regions in Greenland with no known local pollution sources.

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 1982-2007.

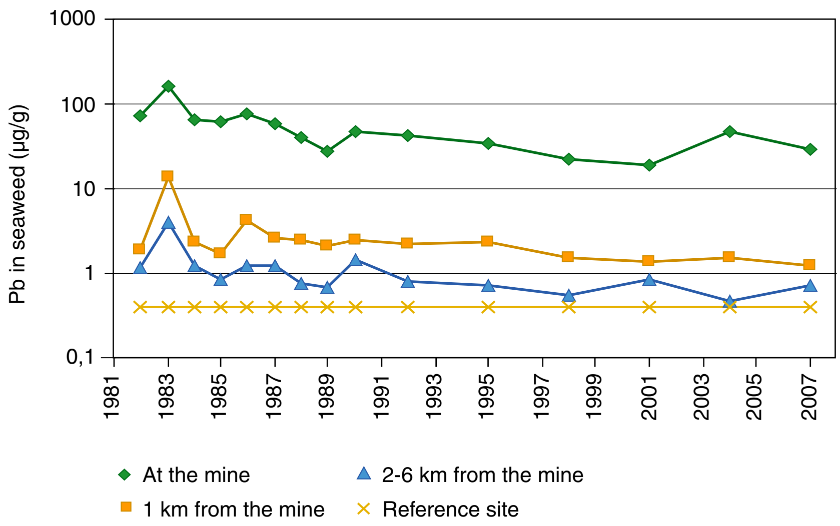


Figure 13. Time trend of the lead concentration in small blue mussels (*Mytilus edulis*) in different groups of stations at Ivittuut 1982-2007.

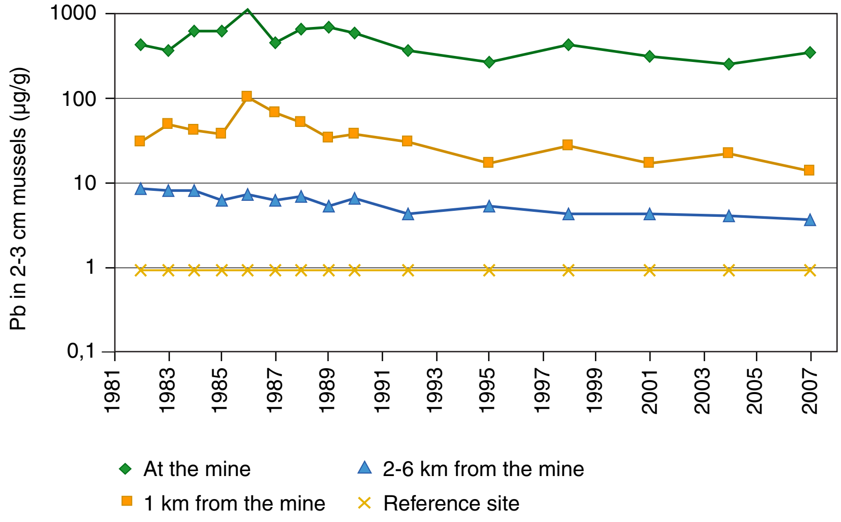


Figure 14. Time trend of the lead concentration in large blue mussels (*Mytilus edulis*) in different groups of stations at Ivittuut 1982-2007.

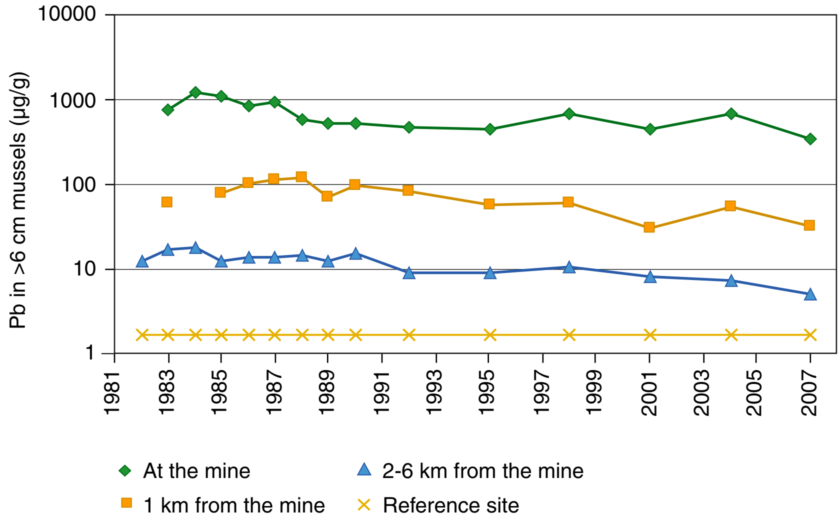


Figure 15. Time trend of the zinc concentration in seaweed (*Fucus vesiculosus*) in different groups of stations at Ivittuut 1982-2007.

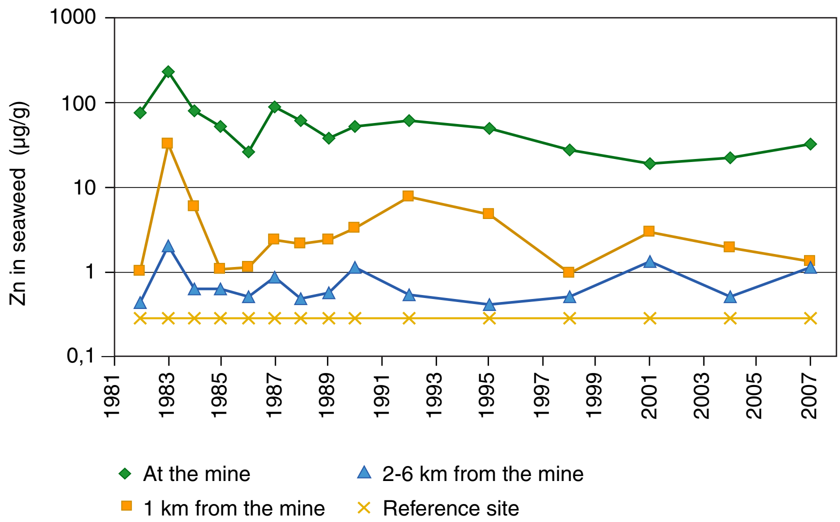
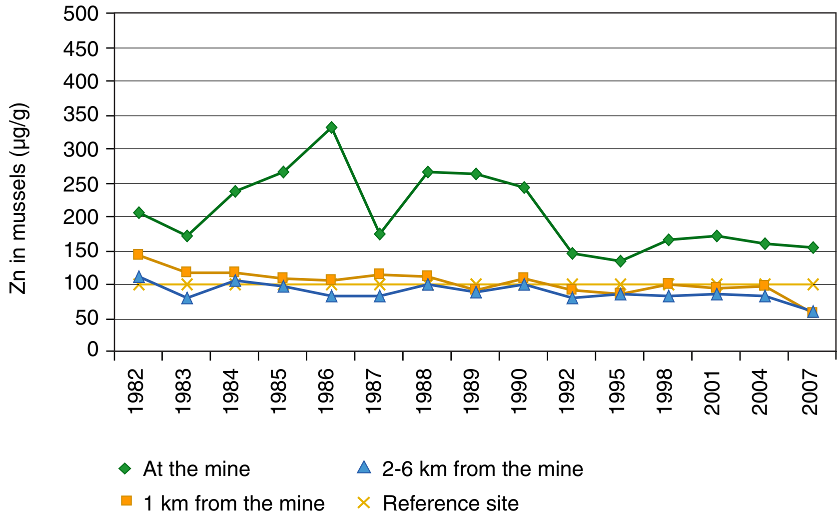


Figure 16. Time trend of the zinc concentration in blue mussels (*Mytilus edulis*) in different groups of stations at Ivittuut 1982-2007.



3.4 Restrictions on 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 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), but will also be exceeded at some distance outside the area delimited by these stations. 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 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).

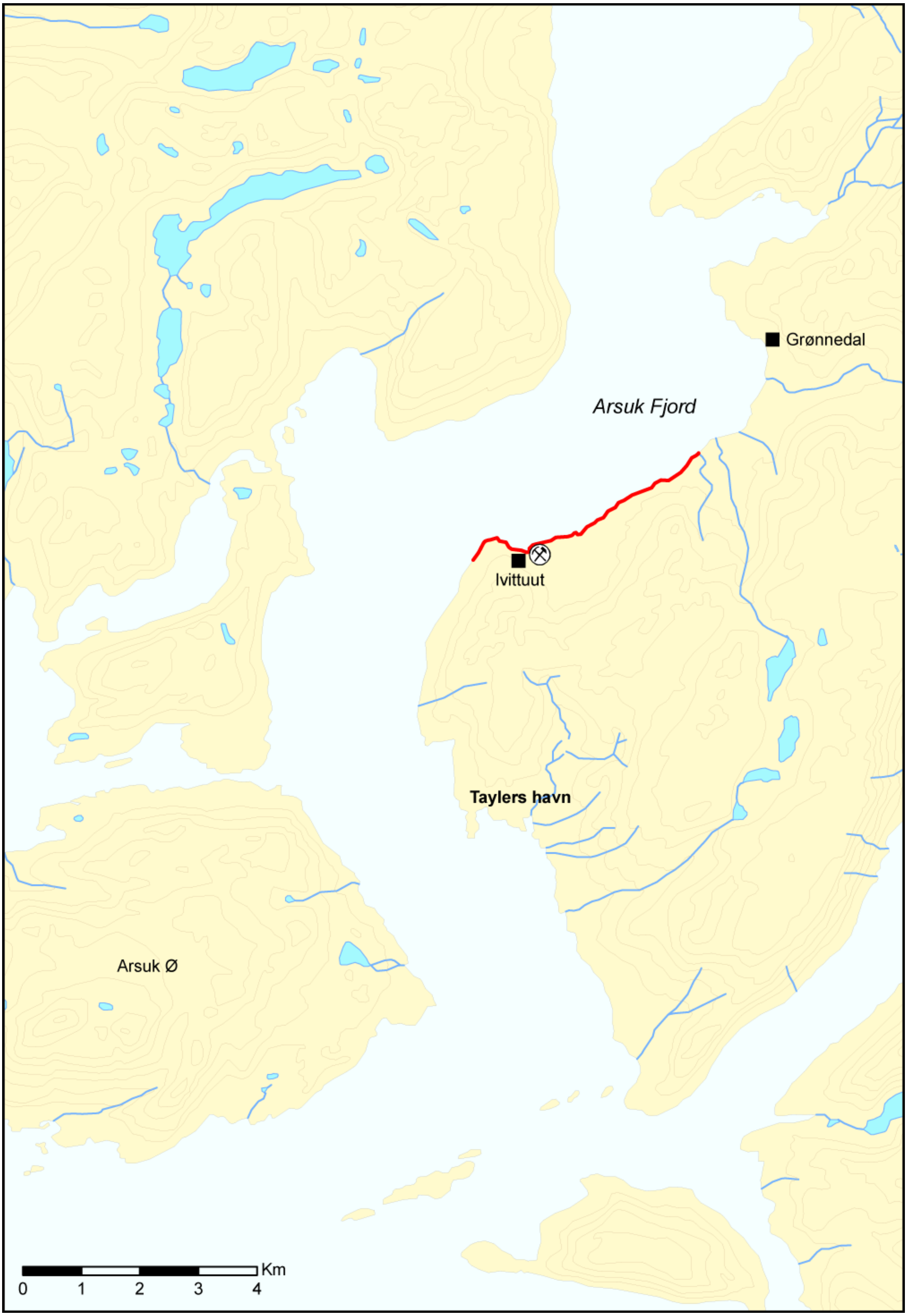


Figure 17. Area where it is recommended not to collect and eat blue mussels.

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Annex 1. Brown seaweed data 2007

Lead and zinc concentrations (µg/g d.w.) in brown seaweed (*Fucus vesiculosus*)

ID #	Station	Pb	Zn
37001	St. 1	0.67	31.8
37001	St. 1	0.69	32.4
37002	St. 1	0.47	22.9
37003	St. 2	0.54	24.7
37004	St. 2	0.46	26.4
37005	St. 3	0.53	28.7
37005	St. 3	0.51	28.5
37006	St. 3	0.62	28.8
37007	St. 4	1.07	28.7
37008	St. 4	1.16	28.8
37009	St. 5	28.46	145.0
37010	St. 5	48.06	179.7
37011	St. 6	21.89	170.9
37012	St. 6	19.19	155.7
37079	St. 8	31.92	236.9
37080	St. 8	30.26	220.0
37081	St. 9	1.34	47.5
37082	St. 9	1.53	41.9
37083	St.10	1.11	40.9
37084	St.10	1.19	42.1
37084	St.10	1.28	43.3
37063	St.11	0.61	35.2
37064	St.11	0.54	40.6
37023	St.12	0.58	35.5
37024	St.12	0.50	32.5
37025	St.13	0.83	35.6
37026	St.13	0.54	25.4
37027	St.15	0.63	27.5
37028	St.15	0.61	20.1
37029	St.16	0.51	20.2
37030	St.16	0.50	27.6
37043	St.17	0.35	28.3
37044	St.17	0.33	28.9
37031	St.20	0.47	19.8
37031	St.20	0.45	19.7
37032	St.20	0.34	17.3
37065	St.21	0.51	34.6
37066	St.21	0.55	24.8
37045	St.22	0.49	29.4
37046	St.22	0.54	38.5
37047	St.24	0.43	25.4
37048	St.24	0.46	23.1
37067	St.27	0.52	22.6
37068	St.27	0.51	22.5
37049	St.28	0.36	20.5
37050	St.28	0.37	20.2

Annex 2. Blue mussel data 2007

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

ID #	Station	Shell length	Number	Mean weight	Dry weight	Pb	Zn
				gram	%	µg/g	µg/g
37013	St. 1	2-3 cm	40	0.62	15.50	2.82	58.1
37014	St. 1	5-6 cm	20	2.51	15.06	4.04	48.1
37015	St. 2	2-3 cm	40	0.51	17.09	3.91	69.5
37016	St. 2	5-6 cm	20	4.93	15.20	4.09	72.1
37017	St. 3	2-3 cm	40	0.45	17.96	6.16	54.6
37085	St. 3	6-7 cm	20	9.05	14.56	5.20	63.0
37019	St. 4	2-3 cm	40	0.48	17.49	13.56	56.5
37086	St. 4	6-7 cm	20	9.22	16.83	31.92	56.3
37021	St. 5	2-3 cm	40	0.61	16.53	172.18	110.7
37087	St. 5	6-7 cm	20	7.29	13.76	259.44	113.7
37088	St. 8	2-3 cm	40	0.49	17.34	505.68	241.0
37089	St. 8	5.9-6.8 cm	19	8.34	16.25	418.89	146.6
37090	St. 10	2-3 cm	40	0.60	17.15	9.81	72.4
37091	St. 10	6-7 cm	20	7.87	14.61	14.95	50.7
37069	St. 11	2-3 cm	40	0.52	15.36	2.78	67.3
37070	St. 11	5.6-6.3 cm	20	5.53	13.85	4.20	50.0
37033	St. 12	2-3 cm	40	0.51	17.66	2.72	66.9
37034	St. 12	6-7 cm	20	8.95	16.36	3.45	56.2
37035	St. 13	2-3 cm	40	0.47	17.63	4.83	55.4
37036	St. 13	6-7 cm	20	8.20	15.10	5.15	48.7
37037	St. 15	2-3 cm	40	0.49	18.25	3.75	58.6
37038	St. 15	5-6 cm	20	4.97	15.69	5.57	55.4
37039	St. 16	2-3 cm	40	0.56	17.75	3.10	59.8
37040	St. 16	6-7 cm	20	7.29	14.53	5.54	53.5
37053	St. 17	2-3 cm	40	0.52	16.37	1.99	79.8
37054	St. 17	6-7.4 cm	20	8.08	13.36	3.41	61.6
37071	St. 19	2-3 cm	40	0.51	16.59	6.16	44.5
37072	St. 19	6-7 cm	20	8.21	15.80	1.76	65.1
37041	St. 20	2-3 cm	40	0.55	18.52	2.50	48.0
37042	St. 20	6-7 cm	19	8.42	13.83	2.24	68.3
37073	St. 21	2-3 cm	20	8.51	14.25	2.26	53.9
37074	St. 21	6-7.4 cm	40	0.48	16.16	3.36	45.3
37055	St. 22	2-3 cm	40	0.57	16.58	2.46	71.4
37056	St. 22	6-7.3 cm	20	9.91	16.43	4.67	56.9
37057	St. 24	2-3 cm	40	0.61	17.45	2.77	74.3
37058	St. 24	5.7-6.8 cm	20	7.84	16.89	3.49	69.3
37075	St. 26	2-3 cm	40	0.57	18.58	1.71	58.0
37076	St. 26	6-7 cm	20	9.03	16.63	3.37	50.4
37077	St. 27	2-3 cm	40	0.56	15.41	2.55	60.3
37078	St. 27	6-7 cm	20	8.37	13.33	3.82	49.3
37059	St. 28	2-3 cm	40	0.58	18.00	1.80	71.7
37060	St. 28	6-7 cm	19	8.63	15.03	3.29	72.1
37061	St. 29	2-3 cm	40	0.56	17.60	1.36	71.6
37062	St. 29	5.1-6.6 cm	20	6.12	15.36	2.60	69.4

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674 Environmental monitoring at the cryolite mine in Ivittuut, South Greenland, 2007

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