ENVIRONMENTAL MONITORING IN 2013 AT THE CRYOLITE MINE IN IVITTUUT, SOUTH GREENLAND

Scientific Report from DCE – Danish Centre for Environment and Energy No. 105 2014

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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 2013. The area is polluted by lead and zinc caused by the mining of cryolite that took place from 1854 to 1987. The 2013 study shows that the lead pollution of the fjord continues to decline. Zinc concentrations also generally decrease, but at a slower rate. Elevated lead concentrations were found in blue mussels in the outer Arsuk Fjord and in areas 3- 4 km outside the Arsuk Fjord. Along a c. 5 km stretch of coastline around Ivittuut, the lead concentration in blue mussels is at a level where it is recommended not to collect mussels for human consumption. Lead and zinc concentrations in brown seaweed are also found elevated in parts of Arsuk Fjord.

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

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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 related to waste rock, which was left at the coastline and is still continuously releasing lead and zinc to the fjord from tidal water action.

The pollution of the fjord has been monitored since 1982. Since 1985 the monitoring has only included brown seaweed and blue mussels, since earlier studies revealed no elevated levels of lead and zinc in fish and prawns from the fjord.

This report presents the results of the latest environmental study, which was carried out in July 2013. The geographical pattern of lead and zinc levels found in brown seaweed and blue mussels in 2013 showed that waste rock deposited at the coastline in Ivittuut is still the main source of the pollution from the old mine. In brown seaweed elevated lead levels were found on a ca. 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 found in all of the studied parts of Arsuk Fjord, and also on coasts 3-4 km outside Arsuk Fjord. Zinc levels in blue mussels were elevated only at Ivittuut.

Along a stretch of coastline of ca. 5 km around Ivittuut the lead concentrations in blue mussels were found at levels so high that it is recommended not to collect blue mussels for human consumption. The size of this area is similar to what was found in 2007 and 2010, but smaller than in 2004 and much smaller than what was found in the period 1982-1992. During the period of 1982-1992 the recommendation not to collect mussels also included part of the western coastline of Arsuk Fjord.

Over the entire monitoring period from 1982 to 2013 a decline in pollution has been observed for lead levels in both brown seaweed and blue mussels in Arsuk Fjord. Whereas lead concentrations have decreased ca. 3 times since 1982, the concentrations of zinc have also generally decreased, but at a slower rate.

Eqikkaaneq

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Qeqqussat Ivittuut eqqaanni kangerluup saqqaani 4 km- missaannik isorartussulimmi nalinginnaasumiit aqerlortaqarneruppput, taavali Arsuup Kangerluani misissuiffigineqartup annersaani qeqqussat nalinginnaasumiit zinkitaqarnerullutik. Uillut Arsuup kangerluani misissuiffinni tamani aammalu Arsuup Kangerluata avataani 3-4 km-inik isorartussusilimmi nalinginnaasumit aqerlortaqarneruppput. Uilut zinkitaqassusiat eqqarsaatigalugu Ivittuut eqqarpiaanniittut kisimik nalinginnaasumiit akoqarneruppput.

Ivittuut eqqaanni sinerissami 5 km missaannik isorartussusilimmi uillut ima aqerlortaqartigipput nerineqarnissaat innersuussutigineqarani. Piffik taama akoqarfiat taanna 2007-imiit 2010-mut misissuisarnerni isorartussutsimisut ippoq kisiannili 2004-imiit minneruvoq, aammalu 1982-1992-imiit assut annikinnerulluni. Piffissami tassani Arsuup Kangerluata alanngua aamma ilanngunneqartarpoq.

Piffissaq misissuiffiusartoq 1982-imiit 2013-imut tamaat qiviaraanni Arsuup Kangerluani qeqqussat uillullu aqerlumik akuat appariartorsimavoq. Maanna 1982-imiit aqerloqassusiat agguaqatigiissillugu pingajorarterutaannanngorsimagaluartoq taamaattoq qeqqussat uillullu zinkeqassusiat apparsimagaluarluni aqerloqassusiattulli appariartigisimanngilaq.

Resumé

I Ivittuut ved Arsuk Fjord i Sydgrønland foregik der brydning, sortering og udskibning af mineralet kryolit i perioden 1854 til 1987. Mineaktiviteterne medførte 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 og 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 2013. Den geografiske fordeling af bly- og zinkkoncentrationen i blæretang og blåmusling i 2013 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 Arsuk Fjord. Zinkværdierne i blåmusling er kun forhøjet i området 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 i 2007 og 2010, men er mindre end ved undersøgelsen i 2004 og meget mindre end i perioden 1982-1992. I perioden 1982-1992 omfattede området også en del af kyststrækningen på den vestlige del af Arsuk Fjord.

Set over hele undersøgelsesperioden fra 1982 til 2013 er blykoncentrationen i både blæretang og blåmusling faldet i Arsuk Fjord. Mens blykoncentrationerne nu i gennemsnit er ca. 3 gange lavere end de var i 1982, er zinkkoncentrationen i tang og musling også faldet, men ikke i samme grad som blykoncentrationen.

1 Introduction

At 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, ca. 15 km west of Ivittuut, and the former Naval Station Grønnedal, ca. 5 km northeast of Ivittuut.

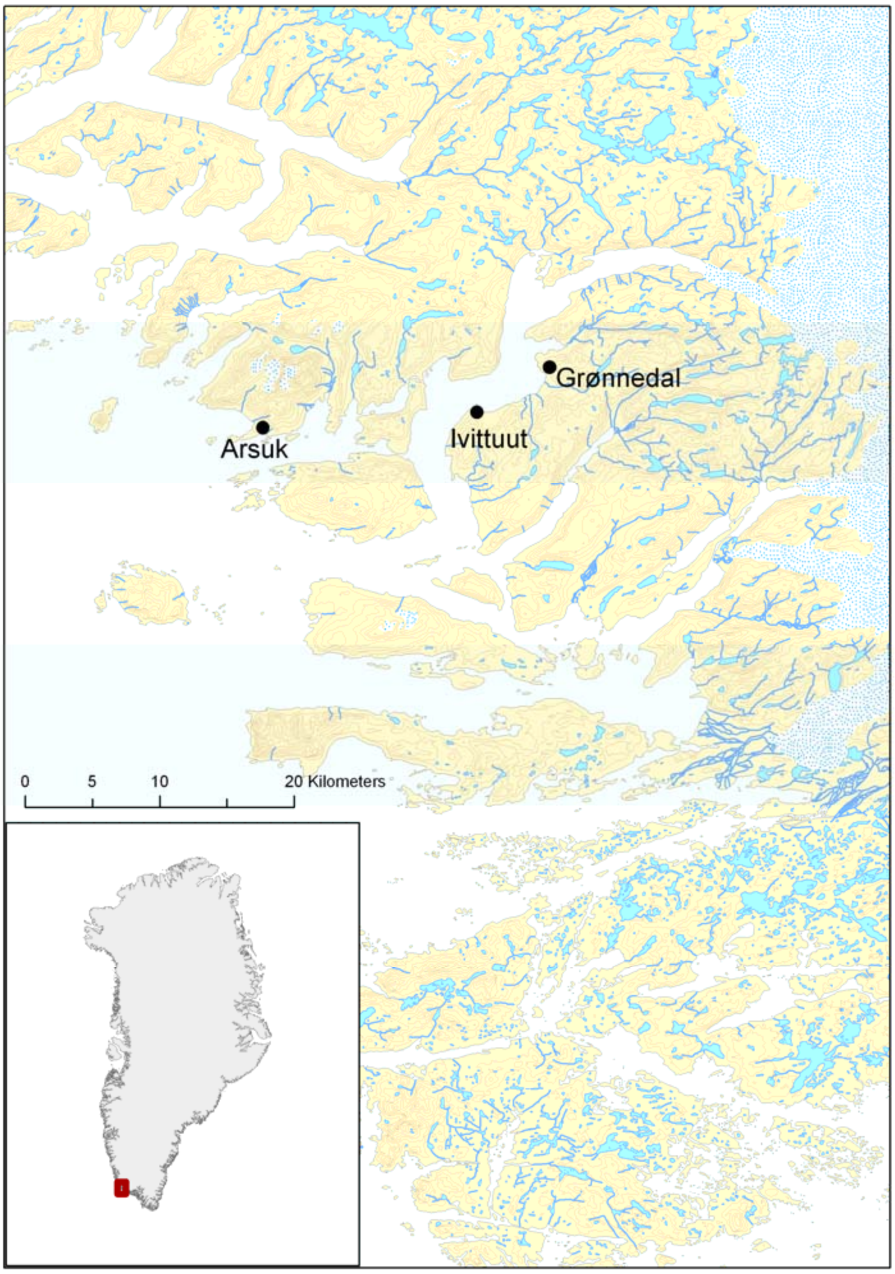


Figure 1. Location of Ivittuut and nearby settlements.

Cryolite is an industrial mineral, which is mainly used in aluminum 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 significant pollution with heavy metals, particularly lead and zinc, which are found in the ore. The most important pollution source was waste rock, which was disposed at the coastline in Ivittuut. The waste rock contains lead and zinc, which continuously is released as dissolved metals to Arsuk Fjord, as the tide moves in and out and reacts with the waste rock. We estimated that in 1985 between 400 and 1,000 kg of dissolved lead annually entered Arsuk Fjord from this source (Johansen et al. 1995). Based on monitoring results on seaweed and blue mussels, it is estimated that the amount of lead released in 2013 is approximately 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 (Johansen et al. 1995; Riget et al. 1995a; Johansen et al. 1998; Johansen & Asmund 2003; Johansen & Asmund 2005; Johansen et al. 2008; Johansen et al. 2010).

The first environmental 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 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 this report we present results from the study conducted at Ivittuut in 2013. We evaluate spatial and temporal trends of lead and zinc pollution within the study area and compare findings with lead and zinc levels found in the same species in uncontaminated regions in Greenland.

2 Sampling and analyses

Sampling of brown seaweed and blue mussels was conducted in the period 1st July to 4th July 2013 by Sigga Joensen and Anna Marie Plejdrup from DCE. A boat was chartered in the Naval Station Grønnedal, where the preparation of samples also was carried out. Sampling stations in the area are shown in Figure 2 and the stations were identical to stations sampled in 2004, 2007 and 2010.

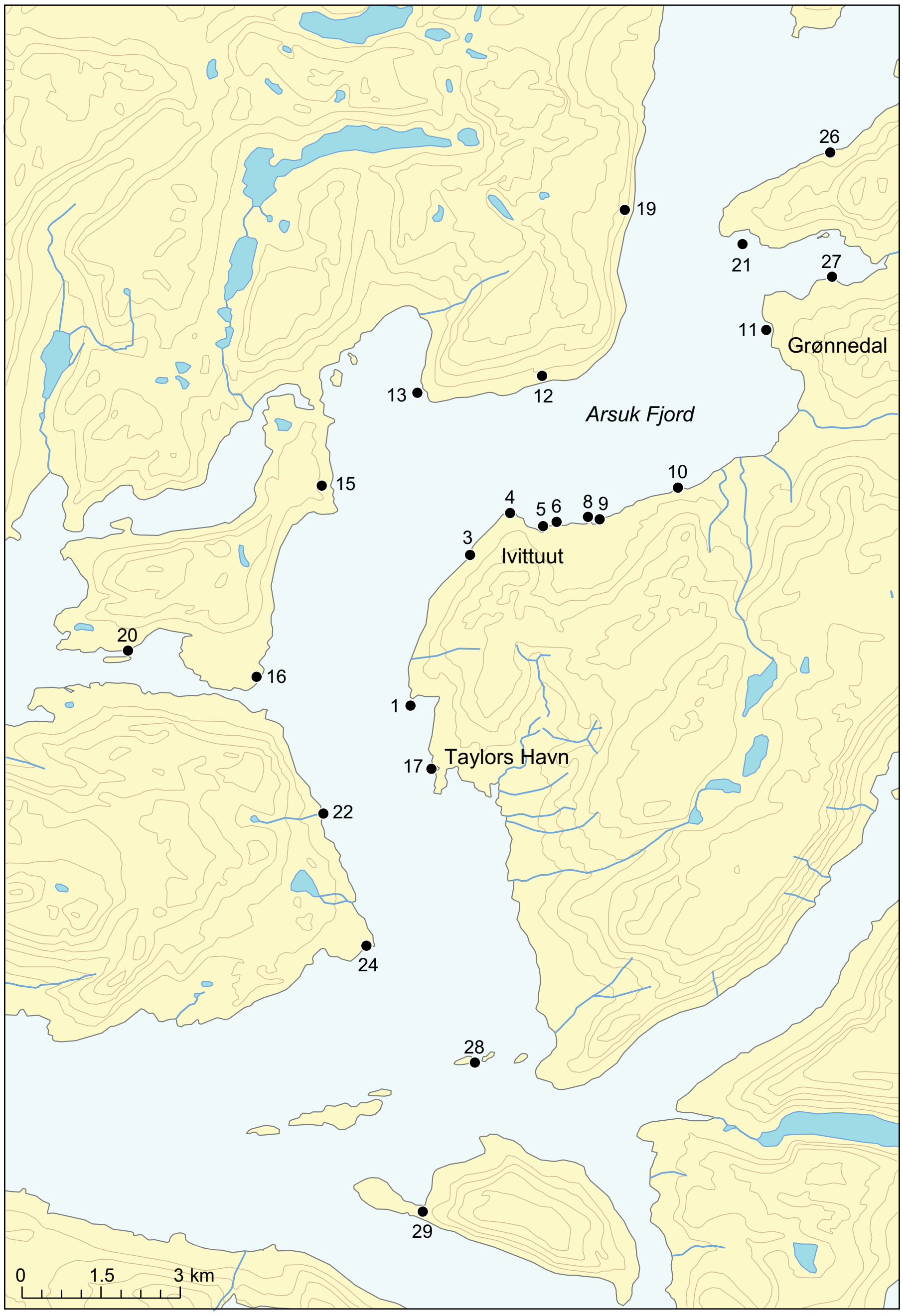


Figure 2. Sampling stations in the area of Ivituut.

Sample treatment as well as analyses were identical to methods used in previous years. At each sample site, two samples of brown seaweed (*Fucus vesiculosus*) were collected at 10 to 30 meters distance in order to account for local variation. The sample consisted of growing tips that were cut of the main plant 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 Bioscience, Roskilde, 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 then determined using flame AAS (Perkin Elmer Analyst 300) and lead concentrations using ICP-MS Agilent. The analytical methods were checked by regularly analyzing the certified reference materials Dorm-4, Dolt-4 and Tort-2. The analytical methods were also checked independently by participation in the intercalibration program QUASIMEME organized by the European Union (results are shown in Annex 2).

Finally, the analytical methods were checked by regularly analyzing the same sample twice. 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 on blue mussels and brown seaweed from the 2013 study are shown in Annex 1.

As described in the methods two samples of brown seaweed were collected at 10 to 30 meters distance in order to account for local variation at each station. In the subsequent presentation and calculation we have used the geometric mean concentration of the two samples.

Earlier studies in Greenland have shown that lead concentrations in blue mussels generally increase with the size of the mussels, whereas this is not the case for zinc (Riget et al. 1996). Therefore, in order to be able to compare lead concentrations in the mussels spatially and temporally, we have sampled and analyzed 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 1). 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.

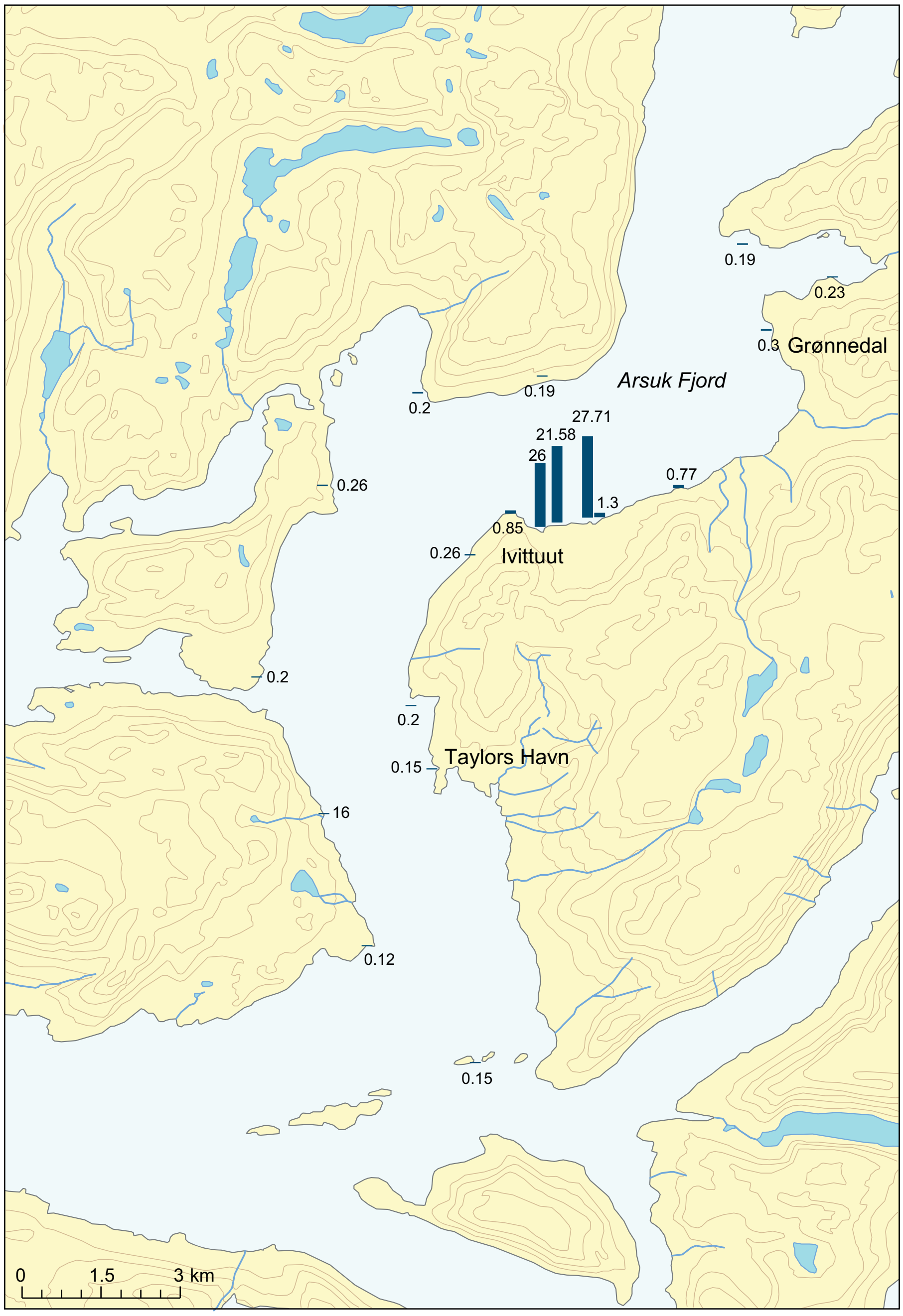
3.2 Spatial trends of lead and zinc concentrations

3.2.1 Brown seaweed

Metal concentrations in seaweed at the stations sampled in the fjord are shown in Figure 3 (lead) and Figure 4 (zinc). These may be compared between stations and with lead and zinc levels found elsewhere in Greenland. Ideally the concentrations should be compared with levels found before the mining started, but no such data exist as the mine started operating in 1854 and this was before environmental awareness. It is likely that lead and zinc levels were elevated locally in the fjords caused by natural release of metals from mineralization.

In uncontaminated areas in Greenland (areas with no known local sources) lead levels have been found in the range of 0.2-0.4 µg/g dry weight and zinc levels in the range of 7-17 µg/g dry weight in brown seaweed (Riget et al. 1993, 1995b). Compared to these concentrations, lead levels in seaweed in the present study were elevated within an area of 2 km from Ivittuut with a factor of 100 times higher compared to seaweed in uncontaminated areas (Figure 3). The size of the affected area is comparable to the size found in 2010, but much smaller than the affected area found before 2010.

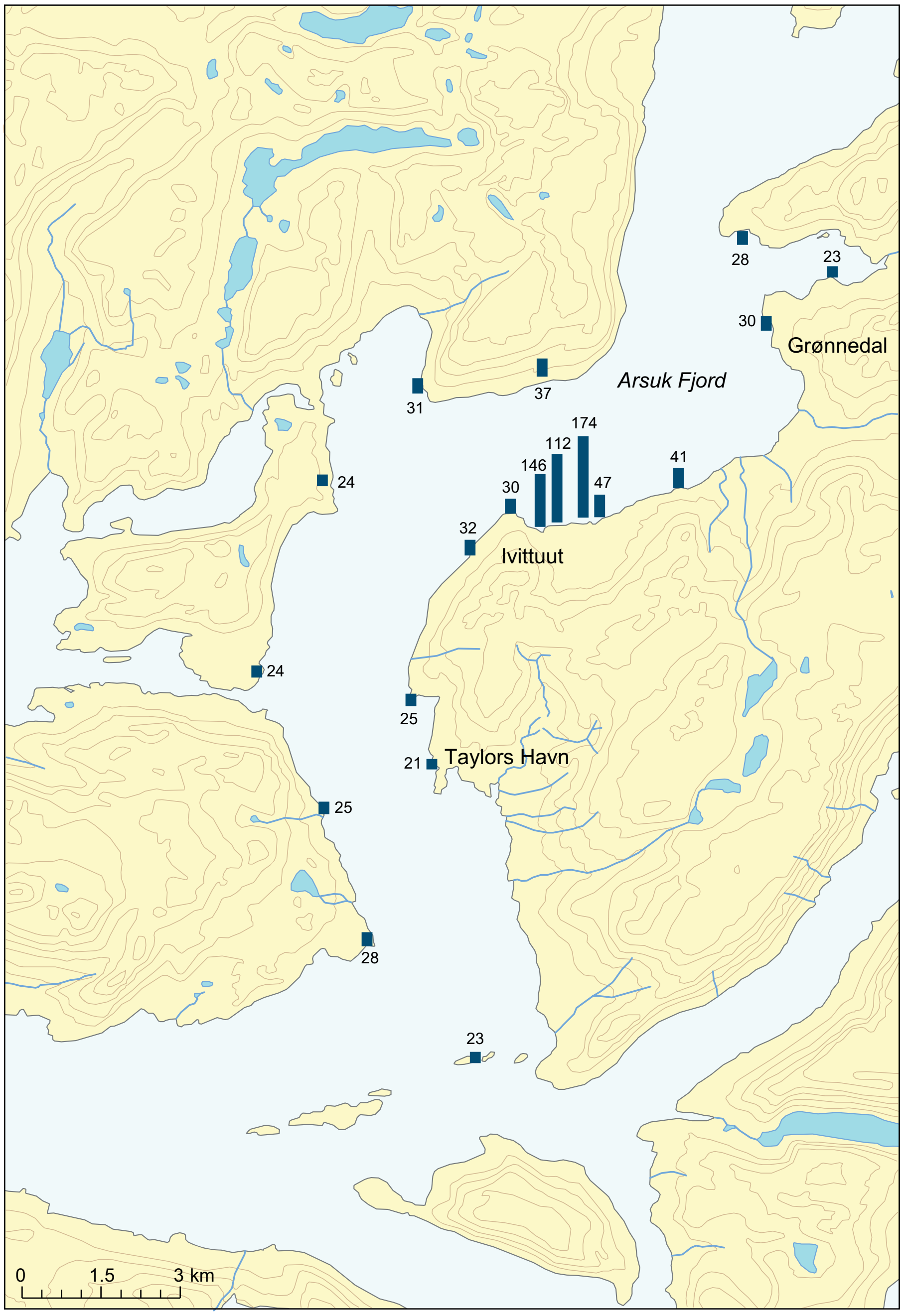
Figure 3. Lead concentration (µg/g dry weight) in brown seaweed (*Fucus vesiculosus*) at Ivittuut in 2013.



In both 2007 and 2010 lead levels in seaweed were elevated in most of the fjord surveyed (Johansen et al. 2008). Compared to those findings the lead levels were lower in 2013, which also is reflected in that the size of the affected area in 2013 was smaller than in 2007 and 2010 and has generally been found to be decreasing during the monitoring period from 1982 until present (see section 3.3 in this report).

In 2013, the zinc pollution is mainly restricted to the area around Ivittuut, where zinc levels are found elevated up to 10 times compared to uncontaminated sites (Figure 4). At all other stations in the study area, zinc concentrations were only slightly elevated compared to uncontaminated sites. Compared to previous years the area which is affected is smaller than previous years (Johansen et al. 2008).

Figure 4. Zinc concentration (µg/g dry weight) in brown seaweed (*Fucus vesiculosus*) at Ivittuut in 2013.



3.2.2 Blue mussels

Lead concentrations in blue mussels sampled in the fjord are shown in Figure 5 (small mussels) and Figure 6 (large mussels). Zinc concentrations in mussels are shown in Annex 2. As with seaweed, the levels from Arsuk Fjord in mussels are compared between stations and with lead and zinc levels found elsewhere in Greenland. Blue mussels collected in Greenlandic areas with no known local pollution sources had 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

In the entire study area lead concentrations were elevated, primarily 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), with a distance of about 15 km south of Ivittuut, lead levels were elevated. In most of the other areas, including Arsuk Fjord, lead levels were elevated about 3-4 times. The highest concentrations were found at Ivittuut where levels were elevated 200-800 times. In mussels, zinc concentrations were found elevated only at station 5 and 8 at Ivittuut and only by a factor of about 2.

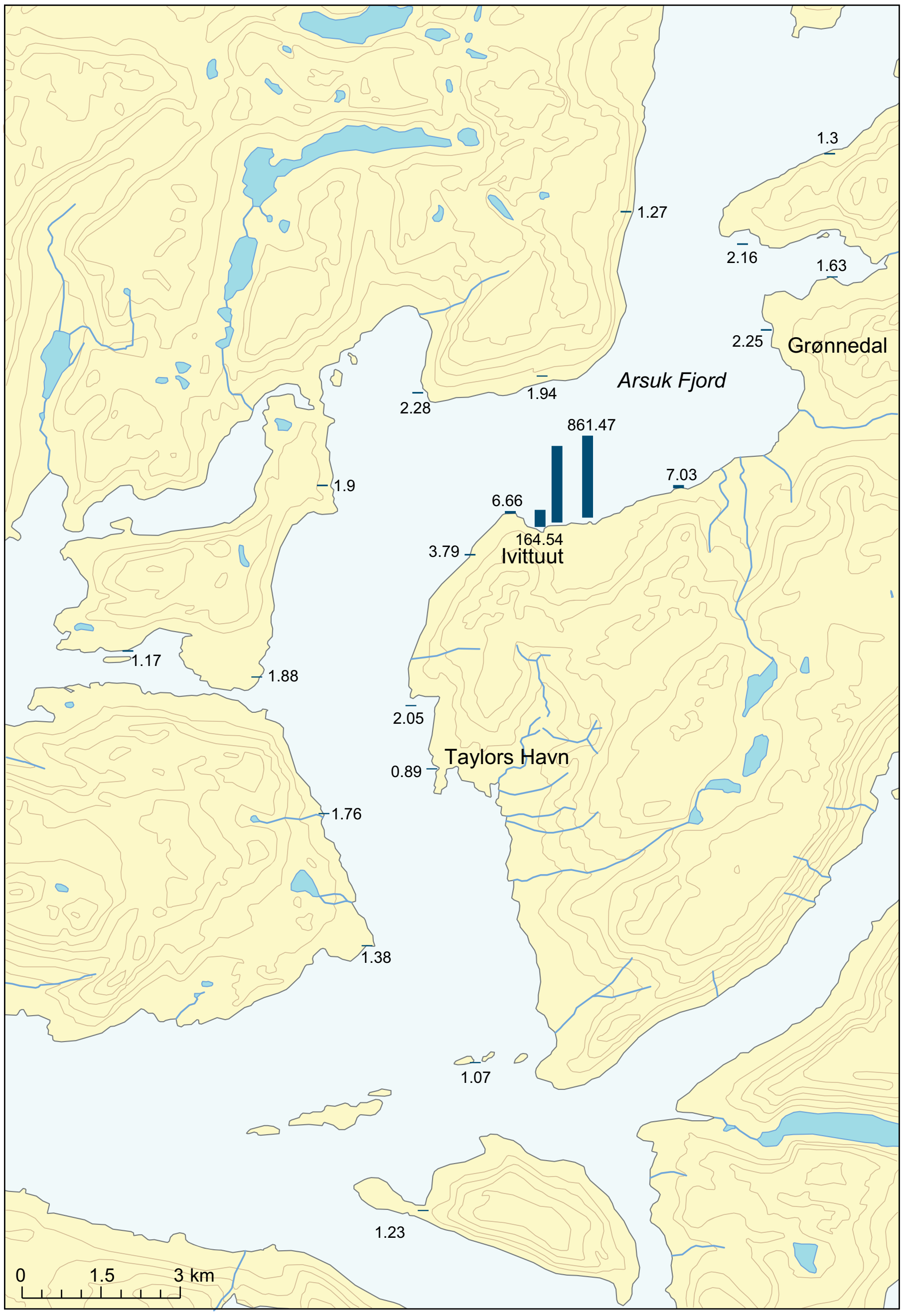
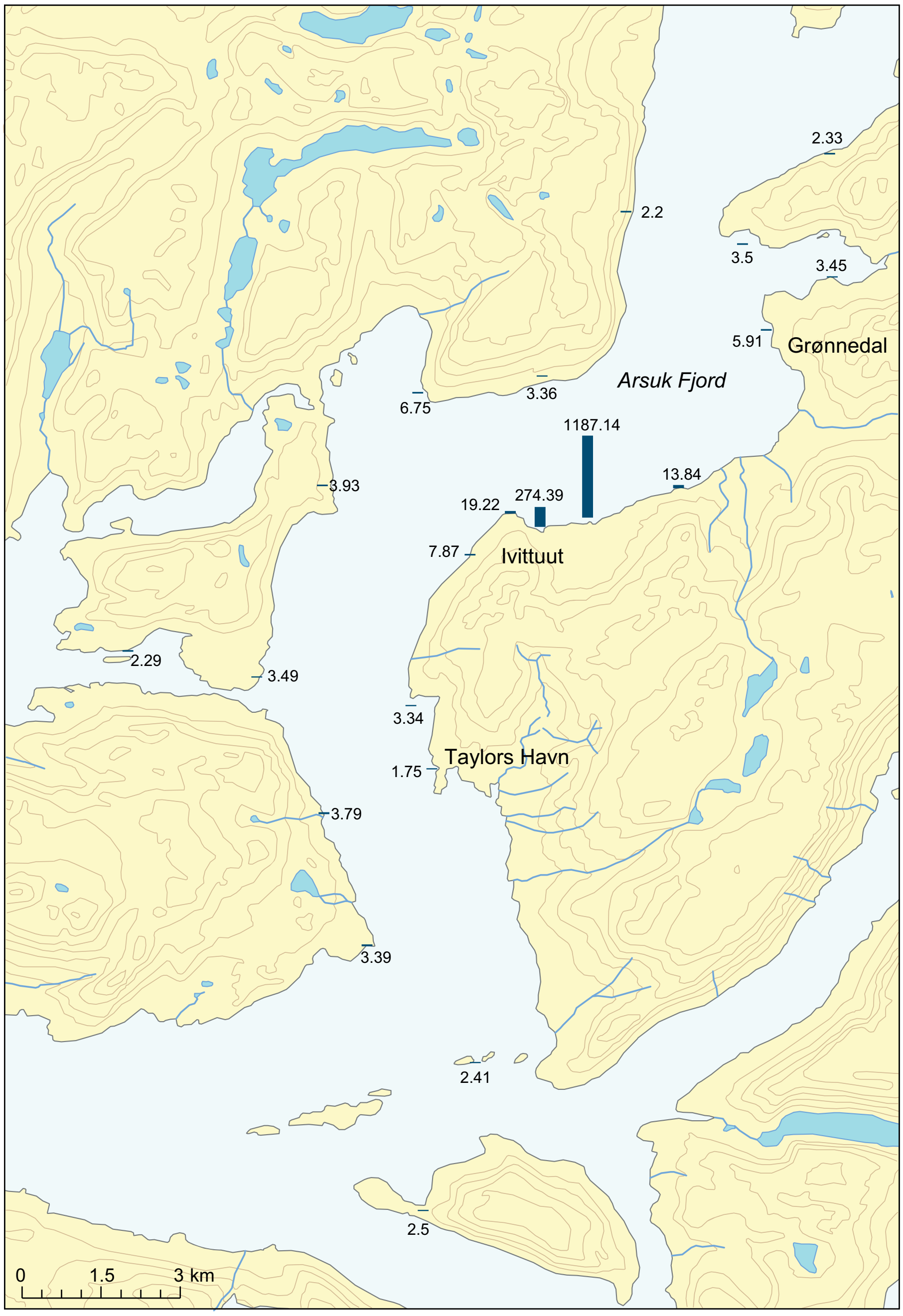


Figure 5. Lead concentration (µg/g dry weight) in small blue mussels (*Mytilus edulis*, 2-3 cm shell length) at Ivittuut in 2013.

Figure 6. Lead concentration (µg/g dry weight) in large blue mussels (*Mytilus edulis*, >6 cm shell length) at Ivittuut in 2013.



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.

It has however not been possible to find the species *Fucus vesiculosus* every time, wherefore the species *Fucus disticus* has been sampled instead. 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 the 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. The separation of 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. In cases where two samples of 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 mean of log-transformed 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 3-years running mean 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 7 and 8, and the results for blue mussels in Table 2, Table 3, Figure 9 and Figure 10.

Table 1. Results of the temporal trend analyses of lead (Pb) and zinc (Zn) concentrations in seaweed for the period of 1982 – 2013 for selected stations. 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**
1 / 1982-2013	sign	-	-5.8%	-	-	+0.3%
3 / 1982-2013	sign	-	-4.3%	-	-	+0.6%
4 / 1982-2013	sign	-	-4.1%	-	-	-1.5%
5 / 1982-2013	sign	-	-4.7%	sign	-	-3.4%
6 / 1982-2013	sign	-	-6.2%	sign	-	-3.0%
8 / 1982-2013	sign	sign	-2.1%	sign	-	-2.2%
9 / 1982-2013	-	-	-3.6%	-	-	-1.6%
10 / 1982-2013	sign	-	-3.9%	-	-	0.0%
11 / 1982-2013	sign	-	-5.3%	-	-	0.0%

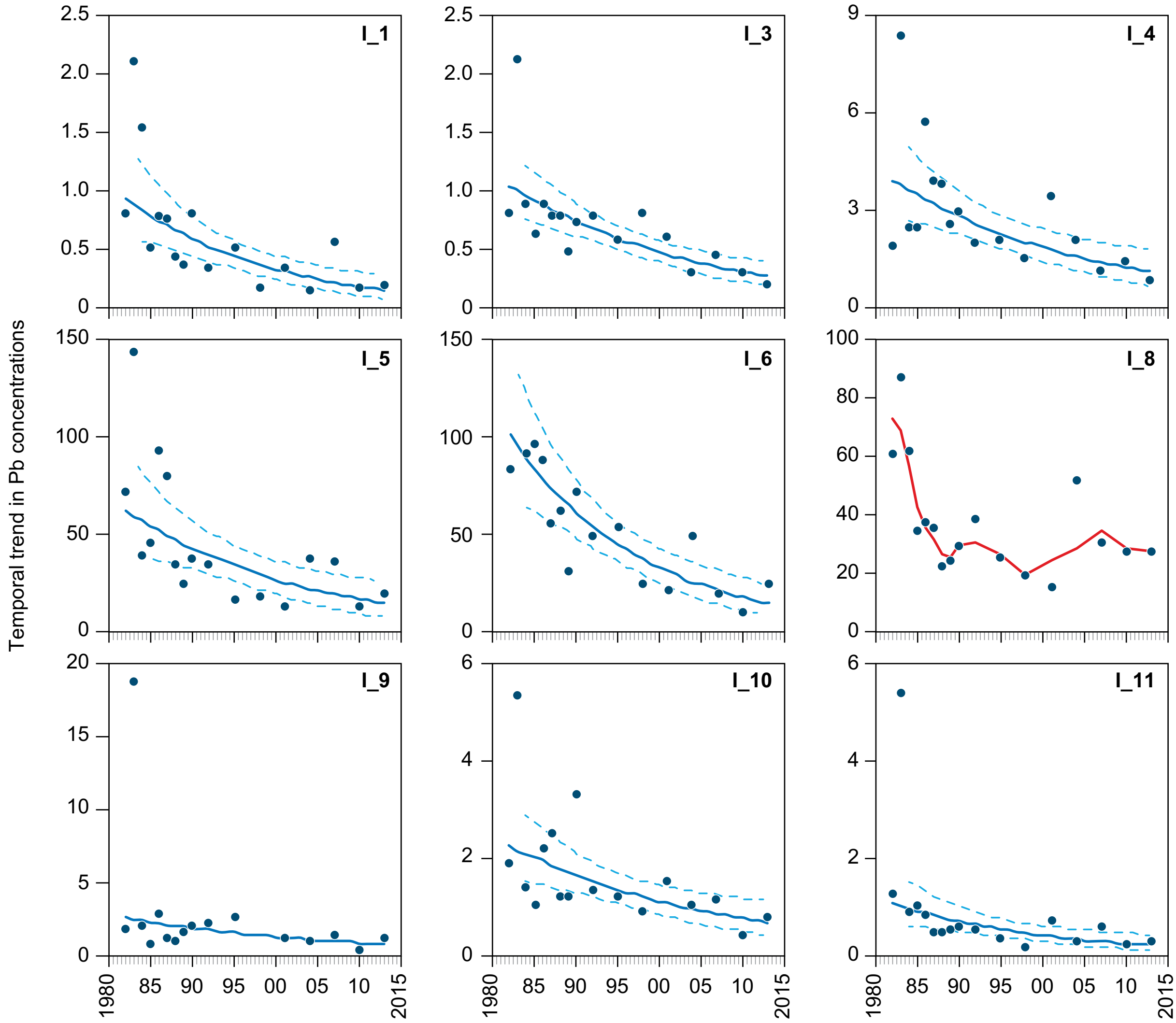


Figure 7. Temporal trend of lead (Pb) concentrations in seaweed from 1982 – 2013 for selected stations. Points denote annual geometric mean concentrations. Solid line together with 95% confidence intervals (broken lines) is given when significant trend was found in the temporal trend analysis. Solid line alone is given when no significant trend was found and red line when the non-linear trend component is significant.

Lead concentrations in seaweed decreased from 2.1 to 6.2 % per year at all stations in the period 1982 to 2013. For all stations, except station 9, the temporal trend was significant at the 5% level. The significant trends could be described as an exponential decrease at all stations, except at station 8, with a non-linear trend, where a sharp decrease in the beginning of the period was followed by a nearly constant level.

No such clear picture is seen for the zinc concentration in seaweed. Levels were significantly decreasing at the stations with the highest concentrations (stations 5, 6 and 8) and the trend could be described as an exponential decrease. Outside the area at Ivittuut zinc concentrations in seaweed remained constant over the whole monitoring period.

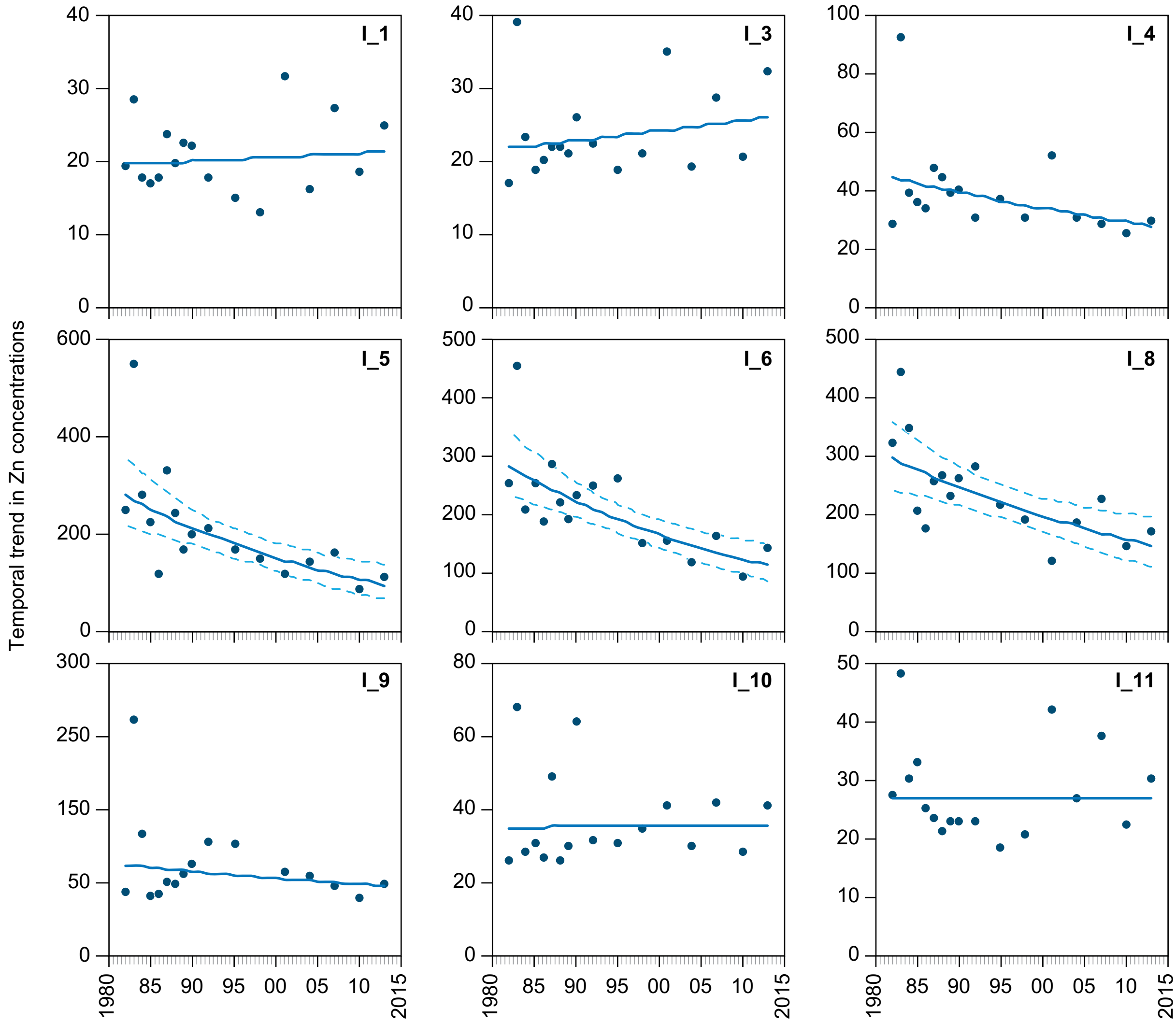


Figure 8. Temporal trend of zinc (Zn) concentrations in seaweed from 1982 – 2013 for selected stations. Points denote annual geometric mean concentrations. Solid line together with 95% confidence intervals (broken lines) is given when significant trend was found in the temporal trend analysis. Solid line alone is given when no significant trend was found.

Lead concentrations in blue mussels decreased in the period 1982 to 2013 at all stations except station 8. The annual rate of decrease during the whole period ranges from no decrease to 6.2 % (Table 2). For the size category 2 to 4 cm, the lead concentrations followed a decreasing exponential curve except at stations 4 and 8 where the non-linear trend component was significant (Figure 9). For size 5 to 8 cm, all temporal trends were significant and following an exponential decrease except at station 4, where lead concentrations peaked in the late 1980'ies then decreased until today (Figure 9). In average for all stations and both size groups the lead has yearly decreased 4.0% which correspond to a factor 3.2 over the 30 years of monitoring. For most stations the temporal trend can be described by an exponential decrease. Stations 4 and 8 are exceptions. In case of 4 there is a local peak around the years 1986 and 1987. The reason for this peak is unknown but may be caused by some local conditions. At 8 the small blue mussels also show a local peak around the years 1986 and 1987 and furthermore show a general increase in the recent years. The larger blue mussels show no significant temporal trend. The two stations are close to the Ivittuut area.

Table 2. Results of the temporal trend analyses of lead (Pb) 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
1 / 1982-2013	sign	-	-3.8%	sign	-	-5.3%
3 / 1982-2013	sign	-	-3.2%	sign	-	-4.4%
4 / 1982-2013	sign	sign	-6.2%	sign	sign	-5.0%
5 / 1982-2013	sign	-	-5.4%	sign	-	-3.1%
8 / 1982-2013	-	sign	+0.4%	-	-	-0.1%
10 / 1982-2013	sign	-	-2.7%	sign	-	-3.4%
11 / 1982-2013	sign	-	-4.8%	sign	-	-4.7%
12 / 1983-2013	sign	-	-4.1%	sign	-	-4.7%
13 / 1983-2013	sign	-	-3.4%	sign	-	-2.8%
15 / 1983-2013	sign	-	-3.6%	sign	-	-3.7%
16 / 1986-2013	sign	-	-4.4%	sign	-	-4.5%
17 / 1983-2013	sign	-	-5.7%	sign	-	-6.2%
21 / 1983-2013	sign	-	-3.7%	sign	-	-4.9%
22 / 1983-2013	sign	-	-3.7%	sign	-	-4.0%
24 / 1983-2013	sign	-	-3.5%	sign	-	-4.1%
27 / 1984-2013	sign	-	-3.3%	sign	-	-3.9%
28 / 1984-2013	sign	-	-3.3%	sign	-	-5.5%

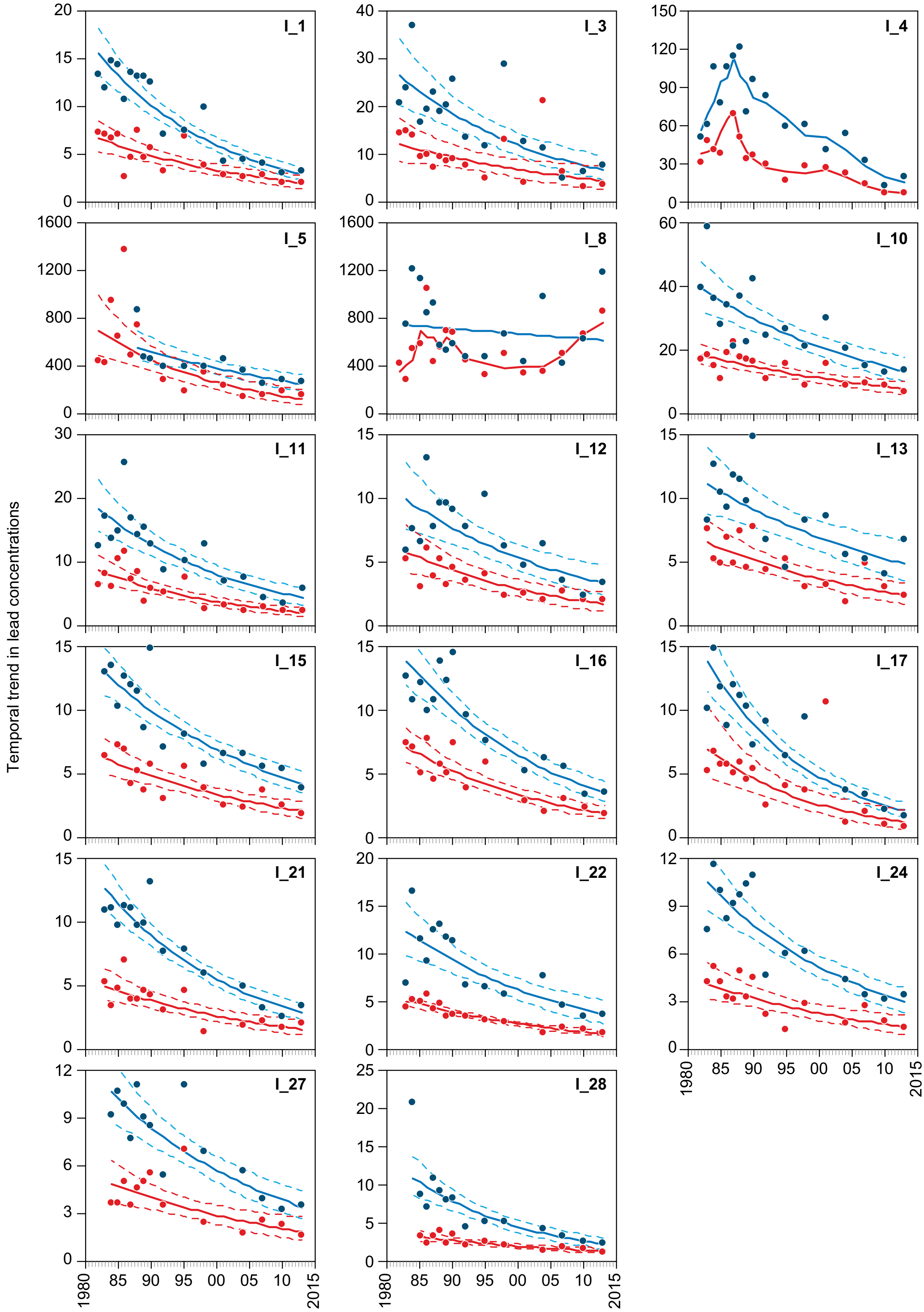


Figure 9. Temporal trends of lead (Pb) concentrations in blue mussels in the period of 1982 – 2013. Red colour denotes results of size group 2 to 4 cm shell length and blue colour denotes results of size group 5 to 8 cm shell length. Points (geometric mean) and solid trend line together with 95% confidence broken lines are given when significant trend was found in the temporal trend analysis. Solid line without 95% confidence lines is given when no significant trend was found. Non-linear line is given when the non-linear trend component is significant.

Zinc concentrations in blue mussels have also decreased but the rate is lower than for lead, and the annual decrease was between 0.1 and 2.4 % between 1982 and 2013 (Table 3). Significant trends following an exponential decrease were found at 13 stations (Figure 10). Significant non-linear trends were found at station 8 and 17, while no trends were found at station 1 and 22. Also at stations with low or no impact (compared to regions in Greenland with no known local pollution sources) the zinc concentrations were decreasing. For most stations the temporal trend can be described by an exponential decrease. Station 8 is an exception with a local peak around the years 1986 and 1987, similar to lead in blue mussels from the same station. This supports that some local conditions have influenced the contaminations of the blue mussels in these years.

Table 3. Results of the temporal trend analyses of zinc (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 whole period is given.

Blue mussel – Zn			
Station/Year	**Log-linear trend**	**Non-linear trend**	**Annual change**
1 / 1982-2013	-	-	-0.1%
3 / 1982-2013	sign	-	-1.3%
4 / 1982-2013	sign	-	-2.1%
5 / 1982-2013	sign	-	-2.4%
8 / 1982-2013	-	sign	-0.3%
10 / 1982-2013	sign	-	-1.1%
11 / 1982-2013	sign	-	-2.3%
12 / 1983-2013	sign	-	-0.7%
13 / 1983-2013	sign	-	-1.2%
15 / 1983-2013	sign	-	-1.0%
16 / 1986-2013	sign	-	-0.9%
17 / 1983-2013	sign	sign	-0.9%
21 / 1983-2013	sign	-	-1.6%
22 / 1983-2013	-	-	-0.7%
24 / 1983-2013	sign	-	-1.0%
27 / 1984-2013	sign	-	-1.6%
28 / 1984-2013	sign	-	-1.3%

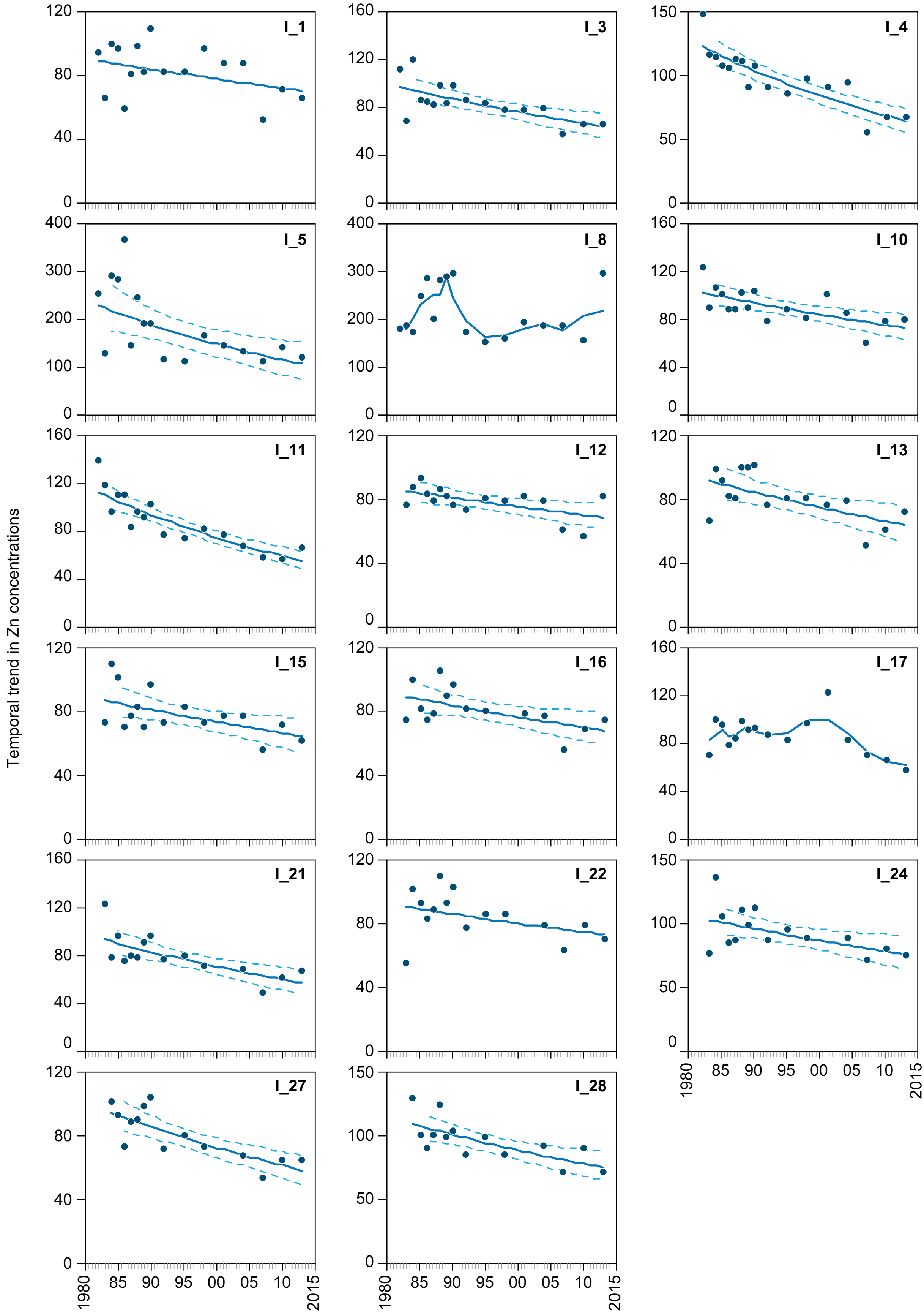


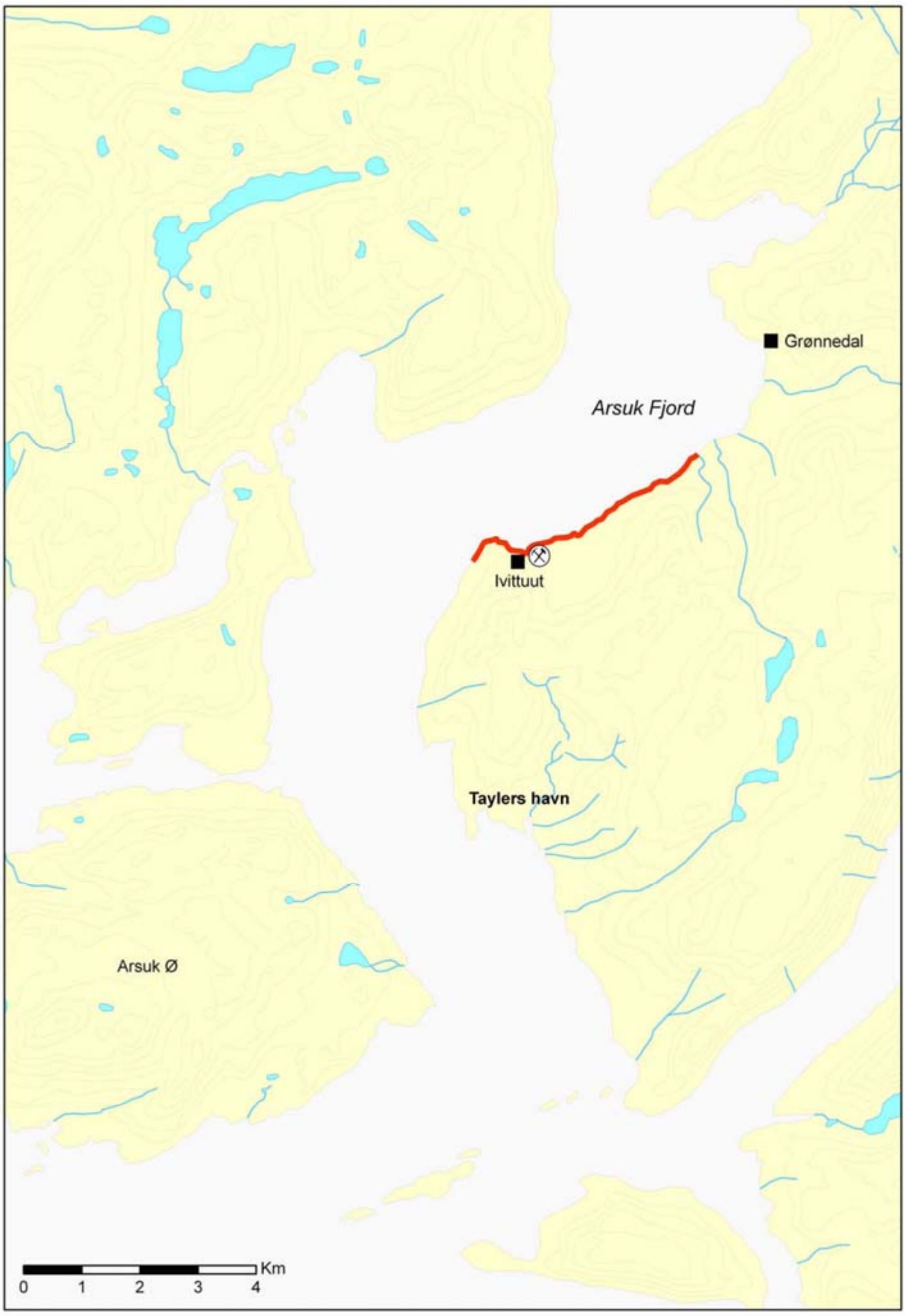
Figure 10. Temporal trend of zinc (Zn) concentrations in blue mussels. Points denote annual geometric mean concentration, Solid line together with 95% confidence broken lines is given when significant trend was found in the temporal trend analysis. Solid line alone is given when no significant trend was found. Non-linear line is given when the non-linear trend component is significant.

3.4 Restrictions for consumption of blue mussels

In Greenland blue mussels are commonly collected locally for human consumption. The finding of elevated lead levels in Arsuk Fjord implies a risk to human health. This risk has been evaluated by comparing the levels found in the fjord with the maximum accepted lead concentration in Greenlandic diet items. For mussels this level is set at 1.5 µg/g wet weight (Rasmussen, 2010). As the mean dry weight percentage in the mussels is roughly 16%, the maximum accepted lead level equals 9.4 µg/g on dry weight basis.

This level is exceeded on station 4, 5, 8 and 10 around Ivittuut (Figure 2) and will also be exceeded at some distance from these stations. In order to define a coastline zone where the 'maximum residue level' is exceeded, and mussels thus should not be collected for consumption, an extrapolation was done between the values found at station 3 and 4 south of Ivittuut and between 10 and 11 north of Ivittuut.

Figure 11. Area where it is recommended not to collect blue mussels for human consumption.



The coastline zone wherein it is recommended not to collect blue mussels for human consumption is shown in Figure 11. The zone is similar to the recommendations in 2007 (Johansen et al. 2008) and 2010 (Johansen at al. 2010). The zone is however smaller than recommendations in 2004 (Johansen & Asmund 2005) and much smaller than in the period 1982-1992, where the recommendations also included part of the western coastline of Arsuk Fjord (Johansen et al. 1995).

4 Conclusion

In brown seaweed elevated lead levels were found on a ca. 4 km stretch of the 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 the studied parts of Arsuk Fjord, and also on the coast line within 3-4 km distance outside the Arsuk Fjord. Zinc levels in blue mussels were elevated only at Ivittuut.

Along a stretch of the coastline of ca. 5 km around Ivittuut the lead concentration in blue mussels were found in so high concentrations that it is recommended not to collect mussels here for human consumption.

The zone is similar to the recommendations in 2007 and 2010, but smaller than the zone proposed in 2004 and much smaller than proposed in the period 1982-1992, where the recommendations also included part of the western coastline of Arsuk Fjord.

Over the entire monitoring period from 1982 to 2013 the pollution has declined for lead in both brown seaweed and blue mussels in Arsuk Fjord. Whereas lead concentrations have decreased ca. 3 times since 1982, the concentrations of zinc have also generally decreased, but at a slower rate.

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Annex 1

Sample type	Station	Size cm	Lat deg	Lat min	Long deg	Long min	dm_%	Pb	Zn
brown seaweed	St 1		61	10,53	48	12,83		0.195	25.1
brown seaweed	St 10		61	12,96	48	8,19		0.765	40.9
brown seaweed	St 11		61	14,57	48	6,9		0.300	30.01
brown seaweed	St 12		61	13,83	48	11,18		0.190	36.7
brown seaweed	St 13		61	13,5	48	13,58		0.197	31.4
brown seaweed	St 15		61	12,49	48	15,19		0.263	24.2
brown seaweed	St 16		61	10,59	48	15,93		0.195	23.7
brown seaweed	St 17		61	9,96	48	12,24		0.145	21.4
brown seaweed	St 21		61	15,35	48	7,61		0.190	28.3
brown seaweed	St 22		61	9,39	48	14,23		0.160	24.6
brown seaweed	St 24		61	8,2	48	13,01		0.120	28.3
brown seaweed	St 27		61	15,16	48	5,75		0.230	23.0
brown seaweed	St 28		61	7,24	48	10,56		0.145	23.4
brown seaweed	St 3		61	12,039	48	12,091		0.255	32.4
brown seaweed	St 4		61	12,49	48	11,42		0.845	30.4
brown seaweed	St 5		61	12,41	48	10,73		21.58	112.4
brown seaweed	St 6		61	12,47	48	10,48		25.98	146.1
brown seaweed	St 8		61	12,556	48	9,881		27.71	174.4
brown seaweed	St 9		61	12,738	48	9,072		1.30	47.1
blue mussel	St 1	2-3	61	10,53	48	12,83	18,68	2.05	71.8
blue mussel	St 10	2-3	61	12,96	48	8,19	17,23	7.03	75.0
blue mussel	St 11	2-3	61	14,57	48	6,9	19,17	2.25	68.4
blue mussel	St 12	2-3	61	13,83	48	11,18	16,02	1.94	77.5
blue mussel	St 13	2-3	61	13,5	48	13,58	16,88	2.28	66.6
blue mussel	St 15	2-3	61	12,49	48	15,19	18,62	1.90	66.7
blue mussel	St 16	2-3	61	10,59	48	15,93	17,11	1.88	65.1
blue mussel	St 17	2-3	61	9,96	48	12,24	19,85	0.890	58.2
blue mussel	St 19	2-3	61	15,51	48	10,0133	19,45	1.27	72.7
blue mussel	St 20	2-3	61	10,66	48	18,53	19,39	1.17	73.5
blue mussel	St 21	2-3	61	15,35	48	7,61	19,28	2.16	70.4
blue mussel	St 22	2-3	61	9,39	48	14,23	19,23	1.76	73.3
blue mussel	St 24	2-3	61	8,2	48	13,01	18,5	1.38	77.4
blue mussel	St 26	2-3	61	16,34	48	6,135	19,53	1.30	71.1
blue mussel	St 27	2-3	61	15,16	48	5,75	17,1	1.63	68.2
blue mussel	St 28	2-3	61	7,24	48	10,56	19,3	1.07	80.9
blue mussel	St 29	2-3	61	5,76	48	11,1567	17,75	1.23	95.5
blue mussel	St 3	2-3	61	12,039	48	12,091	16,98	3.79	67.8
blue mussel	St 4	2-3	61	12,49	48	11,42	20,72	6.66	70.7
blue mussel	St 5	2-3	61	12,41	48	10,73	17,15	164.5	112.7
blue mussel	St 8	2-3	61	12,56	48	9,88	17,43	861.4	339.8
blue mussel	St 1	6-7	61	10,53	48	12,83	17,55	3.34	61.0

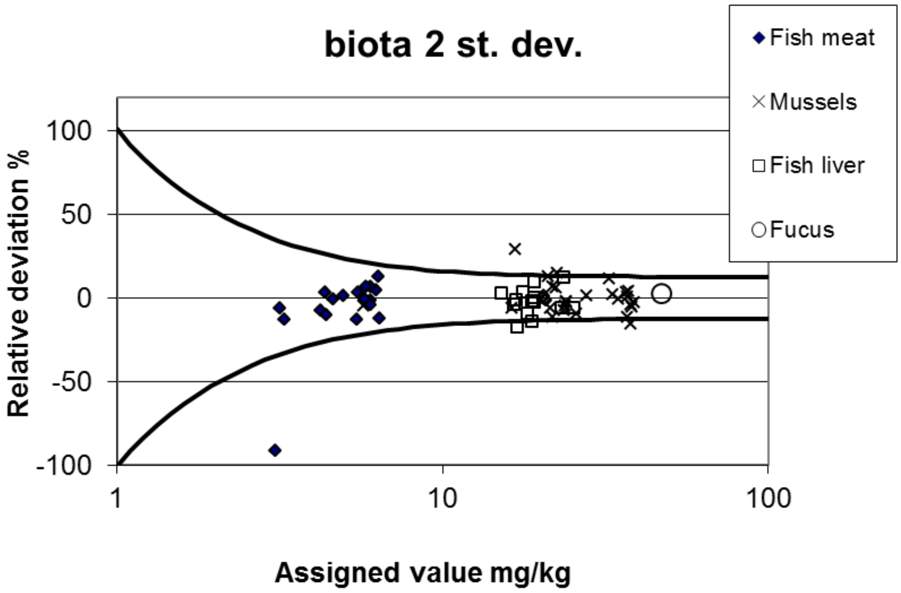
blue mussel	St 10	6-7	61	12,96	48	8,19	16,16	13.8	86.0
blue mussel	St 11	6-7	61	14,57	48	6,9	14,97	5.91	64.9
blue mussel	St 12	6-7	61	13,83	48	11,18	14,22	3.36	88.5
blue mussel	St 13	6-7	61	13,5	48	13,58	12,6	6.75	78.6
blue mussel	St 15	5-8	61	12,49	48	15,19	17,31	3.93	58.6
blue mussel	St 16	6-7	61	10,59	48	15,93	16,69	3.49	84.2
blue mussel	St 17	6-7	61	9,96	48	12,24	16,03	1.75	56.9
blue mussel	St 19	6-7	61	15,51	48	10,0133	16,14	2.20	59.0
blue mussel	St 20	6-7	61	10,66	48	18,53	16,05	2.29	70.1
blue mussel	St 21	6-7	61	15,35	48	7,61	15,73	3.50	65.0
blue mussel	St 22	6-7	61	9,39	48	14,23	17,79	3.79	69.6
blue mussel	St 24	6-7	61	8,2	48	13,01	14,75	3.39	73.2
blue mussel	St 26	6-7	61	16,34	48	6,135	15,26	2.33	70.9
blue mussel	St 27	6-7	61	15,16	48	5,75	13,83	3.45	63.2
blue mussel	St 28	6-7	61	7,24	48	10,56	16,04	2.41	65.6
blue mussel	St 29	6-7	61	5,76	48	11,1567	14,84	2.50	81.9
blue mussel	St 3	6-7	61	12,04	48	12,091	15,15	7.87	65.7
blue mussel	St 4	6-7	61	12,49	48	11,42	17,53	19.2	66.4
blue mussel	St 5	6-7	61	12,41	48	10,73	13,84	274.4	131.1
blue mussel	St 8	6-7	61	12,56	48	9,881	14,18	1187	256.5

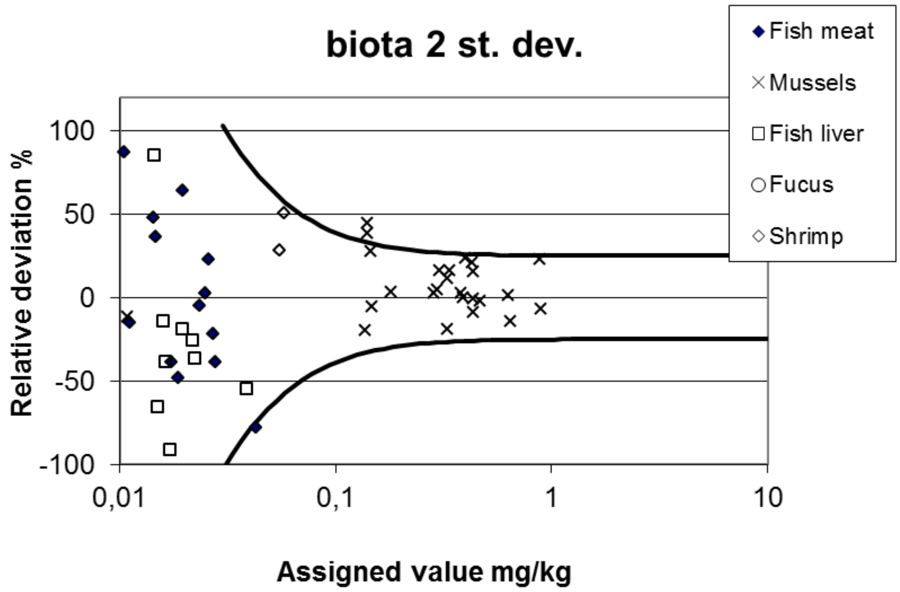
Annex 2

In the QUASIMEME 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 Bioscience's participation in QUASIMEME. In the figure, Bioscience'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 Bioscience 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, Bioscience found lower concentrations than the "indicative assigned values". For zinc the uncertainty by Bioscience is in almost all cases within 12.5%.

Figures. Results for lead (above) and zinc (below) from Bioscience-Roskilde participation in the QUASIMEME laboratory study program. 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.





ENVIRONMENTAL MONITORING IN 2013 AT THE CRYOLITE MINE IN IVITTUUT, SOUTH GREENLAND

This report evaluates the pollution in Arsuk Fjord at Ivittuut in South Greenland based on environmental studies conduc-ted in 2013. The area is polluted by lead and zinc caused by the mining of cryolite that took place from 1854 to 1987. The 2013 study shows that the lead pollution of the fjord continues to decline. Zinc concentrations also generally decrease, but at a slower rate. Elevated lead concentrations were found in blue mussels in the outer Arsuk Fjord and in areas 3- 4 km outside the Arsuk Fjord. Along a 5 km stretch of coastline around Ivittuut, the lead concentration in blue mussels is at a level where it is recommended not to collect mussels for human consumption. Lead and zinc concentrations in brown seaweed are also found elevated in parts of Arsuk Fjord.

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