ENVIRONMENTAL MONITORING AT THE NALUNAQ GOLD MINE, SOUTH GREENLAND, 2013

Scientific Report from DCE – Danish Centre for Environment and Energy No. 97 2014

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Data sheet

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Abstract: This tenth environmental monitoring was conducted in the Nalunaq area, about 40 km from Nanortalik, South Greenland from 27 August to 7 September 2013. The environmental monitoring is conducted to discover and avoid unwanted impacts of the mining industry to the environment. Since the monitoring in 2012 the mining company Angel Mining Gold A/S has been breaking new ore and the mining activities have primarily been contained inside the mountain. The gold was recovered by the use of chemical extraction (carbon-in-pulp) using cyanide. Due to the use of cyanide to extract gold from the ore strict control with the outflow of cyanide from the mine to the Kirkespir Valley is performed. Also an extensive monitoring is conducted to reveal spreading and effects of metals into the Kirkespir Valley and Bay environment. The environmental impact from spreading of metals in the environment of the Kirkespir Valley and Bay, terrestrial, freshwater and marine, due to mining is considered to be minor and decreasing; and there is no requirement for further actions to reduce the environmental impact.

Keywords:	Environment, monitoring, metals, cyanide, blue mussel, brown seaweed, shorthorn sculpin, Arctic char, lichen, transplantation, Nalunaq Gold Mine, Greenland
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Summary

This tenth environmental monitoring programme was conducted in the Nalunaq area, about 40 km from Nanortalik, South Greenland, from 27 August to 7 September 2013. The environmental monitoring programme is conducted to discover pollution from the mining industry to the environment. Since the monitoring survey in 2012, the mining company Angel Mining Gold A/S has continued to break ore in the mine. The gold was recovered by the use of chemical extraction (carbon-in-pulp) with the use of cyanide. Due to the use of cyanide to extract gold from the ore, there was strict control with the outflow of cyanide from the mine to the valley.

Blue mussels, seaweed and sculpins were collected at 4-5 stations in the Kirkespir Bay, Arctic char were caught in Kirkespir River, and lichens, *Flavocetraria nivalis*, were collected at 24 stations in Kirkespir Valley and around the bay area. Lichens were also transplanted from an unpolluted area (AMIT) to the Kirkespir area. All samples were analyzed for 12 metals: arsenic (As), gold (Au), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), mercury (Hg), nickel (Ni), lead (Pb), selenium (Se) and zinc (Zn). The results were compared with background levels measured in 1998-2001 and with the results of previous monitoring studies.

In the terrestrial environment, lichens from the area at the former deposit of crushed waste rock and the mine and camp area have significantly elevated concentrations of Cu, Cr, As and Co compared to background levels, but compared to previous years, the concentrations are decreasing. This year the metal concentration on lichens from the pier area, which formerly served as a depot for ore, have decreased and are no longer significantly different from background concentrations. Overall the metal impact to the terrestrial environment was lower in 2013 compared to 2012. The elevated element concentrations are due to dust dispersal from gravel road, mining activities related to outdoor crushing at the 300 m portal and waste rock deposition on the mountain.

The concentrations of Cu, Cr, As, and Co in the lichens along the gravel road were examined for the period 2005 to 2013. The concentrations were significantly highest close to the gravel road. Concentrations of As in lichens could be found above the background level until a distance of about 1500 m from the road, while concentrations of Co, Cr and Cu met the background level about 400, 140 and 80 m from the road, respectively.

Metals were measured in the freshwater system of the mining area upstream the camp, at the water discharge of the mining wastewater, in the settlement pond, and further downstream in the Kirkespir River. There were elevated concentrations of several metals in the mining wastewater discharge compared to upstream concentrations. After the settlement pond all concentrations of metals could meet the water quality criteria and no elevated metal concentrations could be found in livers of Arctic char.

Kirkespir River runs out into Kirkespir Bay, where blue mussels, seaweed and sculpins were collected. In 2013, the marine environment was only slightly affected by mining activities. Seaweed and mussels were impacted by the outflow of metals by the Kirkespir River in terms of slightly elevated

concentrations of most metals, particularly at the marine stations closest to the estuary. No significantly elevated element concentrations were found in sculpin livers at any of the marine stations.

The dispersal of metals from mining is considered to be minor and decreasing and there is no requirement for further actions to reduce the environmental impact.

By November 2013, the mine closed and a local contractor has taken over the clean-up and restoration of the area, which is expected to be completed by summer 2014. With the closure of the mine, it is expected that the element concentration in the environment due to the mining activity will decrease even further. A small increase in dust dispersal can, however, be expected during clean-up and restoration of the landscape in 2013/2014.

Environmental monitoring will continue at least three years after the closure and is currently planned to take place in 2014, 2015 and 2016.

Sammenfatning

Dette tiende miljøovervågningsprogram blev gennemført i Nalunaq-området, omkring 40 km fra Nanortalik, Sydgrønland, 27. august til 7. september 2013. Miljøovervågningsprogrammet udføres for at opdage forurening fra mineindustrien til miljøet. Efter overvågningen i 2012 har mineselskabet Angel Mining Gold A/S fortsat brudt malm i minen. Guldet udvindes ved anvendelse af kemisk ekstraktion (carbon-in-pulp) ved anvendelse af cyanid. På grund af anvendelsen af cyanid føres der skarp kontrol med, om der strømmer cyanid fra minen til Kirkespirelven.

Blåmuslinger, tang og ulke blev indsamlet på 4-5 stationer i Kirkespirbugten, fjeldørred blev fanget i Kirkespirelven og snekruslav blev samlet på 24 stationer i Kirkespirdalen og ved bugten. Laver blev transplanteret fra et uforurenet område (AMIT) til Kirkespirdalen området. Alle prøver blev analyseret for 12 elementer: arsen (As), guld (Au), cadmium (Cd), cobalt (Co), krom (Cr), kobber (Cu), jern (Fe), kviksølv (Hg), nikkel (Ni), bly (Pb), selen (Se) og zink (Zn). Resultaterne er sammenlignet med baggrundsniveauer målt i prøver indsamlet i 1998-2001 og med resultaterne af tidligere moniteringsstudier.

I det terrestriske miljø, viste lav fra områderne ved depotet for knust gråbjerg, ved minen og lejren signifikant forhøjede koncentrationer af Cu, Cr, As og Co i forhold til baggrundsniveauer, men sammenlignet med de tidligere år var koncentrationerne faldende som i de foregående år. I 2013 var metalpåvirkningen på lav i området ved molen, som tidligere fungerede som malmdepot, faldet sammenlignet med tidligere år, og ingen metalkoncentrationer overskred baggrundsværdierne. Samlet set var metalindholdet i det terrestriske miljø lavere i 2013 end i 2012. Da grusvejen er en kilde til spredning af metalstøv, blev lavernes indhold af metaller relateret til afstanden fra vejen. Koncentrationer af As i laver over baggrundsniveauet kunne findes indtil omkring 1500 m fra vejen, mens koncentrationer af Co, Cr og Cu nåede baggrundsniveauet omkring henholdsvis 400, 140 og 80 m fra vejen.

Både i vand og sedimenter var der forhøjede metalkoncentrationer i spildevandet fra minen. Nedenfor sedimentationsbassinet, var vandkvalitetskriterierne opfyldt for alle metaller, og der var ingen tegn på forhøjede metalkoncentrationer i lever fra fjeldørred ved vandfaldet i Kirkespirelven.

Kirkespirelven ender i Kirkespirdalen Bugt, hvor blåmuslinger, tang og ulke blev indsamlet. Det marine miljø var i 2013 kun lidt påvirket af minedriften. Både tang og muslinger var påvirkede af udledning af metaller fra Kirkespirelven i form af let forhøjede koncentrationer af de fleste metaller, især på de marine stationer tættest på elvmundingen. Der blev dog ikke fundet signifikant forhøjede metalkoncentrationer i ulkelever fra de marine stationer.

Miljøbelastningen i Kirkespirdalen og Kirkespirbugten vurderes at være begrænset og faldende, og der vurderes ikke at være behov for yderligere miljømæssige tiltag hverken i forhold til det terrestriske miljø, i ferskvand eller i det marine miljø.

I november 2013 lukkede minen og en lokal entreprenør har overtaget oprydning og naturgenopretning af området. Oprydning og genopretning forventes at være afsluttet i sommeren 2014. Med lukningen af minen forventes det, at koncentrationerne af metaller i miljøet vil falde yderligere. En lille stigning i støvspredning kan ikke udelukkes under oprydning og naturgenopretningen i 2013/2014.

Miljøovervågningen vil fortsætte mindst 3 år efter lukningen og er foreløbig planlagt til at finde sted i 2014, 2015 og 2016.

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1 Introduction

1.1 Mining activities

'Nalunaq' is the Greenlandic name of Greenland's first gold mine and means 'the place that is hard to find'.

The mine is now closed and remediation is taking place. The closure was announced in October 2013 and the mine was left by personnel by 15 November 2013 and remediation by a local constructing company began.

The Nalunaq Gold Mine is located in Kirkespir Valley 40 km northeast of Nanortalik at the southernmost tip of Greenland. The deposit is a Proterozoic narrow-vein, high-grade gold deposit. Nalunaq Mountain, which hosts the gold deposit, is located in a wide glacial valley reaching into the Saqqaa Fjord about 9 km from the mine site. The terrain is a glacial valley with mountain peaks reaching 1,200-1,600 m above sea level. A river runs through the valley, fed by mountain streams of melting snow.

Nalunaq started the production in 2004, and until 2009 there was only mining and shipping of ore. In 2009, the production changed with the aim of full production of doré in Nalunaq. Most of the mining work from 2009 and until the actual production in 2011 dealt with the excavation of a production chamber inside the mine and the preparation of a chemical gold separation (Carbon-In-Pulp, CIP) including cyanide use and optimization of the processes. The CIP method employed large tanks aligned whereby gold was dissolved into slurry (pulp) through a chemical process incorporating agitation, oxygen and cyanide. Once dissolved, the gold in aqueous solution required separation. At this stage, activated carbon pellets were introduced to the circuit. Activated carbon is charged in such a way that it adsorbs the aqueous gold. The gold loaded coarse grained carbon could then be screened from the water and the fine grained ore. The loaded carbon was then introduced to a cyanide solution under heat and pressure with the purpose of stripping the gold from the carbon. Subsequently, the gold was electroplated onto stainless steel cathodes and melted into doré bars. The metallurgists strived for the best recovery with the least loss of gold from the circuitry through tailings, and the CIP process lead to an app. 90% recovery of gold from the ore. Since the first pure of gold in August 2011, the Nalunaq Mine has till the end produced more than 670 kg of doré.

As described above the gold extraction involved addition of cyanide. Cyanide is, however, a compound that exerts high acute toxic effects even in low concentrations, but is easily degraded under light and/or oxygen to nontoxic levels. In the mining process cyanide was added in the first extraction tank as sodium cyanide. After its use the cyanide was treated by sodium metabisulphite and air in order to decompose the cyanide into cyanate. The cyanide was, however, not decomposed completely, and the rest of the cyanide followed the tailings into the under-ground tailings chamber where the water is subjected for recirculation to the process. A small amount of cyanide was discharged by wastewater from the process.

Associated to the mining process there were in particular two main environmental risks:

- The risk of spreading of released metals due to the crushing effects of the body rock, deposition of waste-rock and driving on the gravel road. The environmental risks were associated with discharge of wastewater from the process and to spreading of metals as dust particles.
- The risk of discharge of cyanide in toxic concentrations to the environment. The risks were associated with discharge of mining process waste water or accidental spills of cyanide e.g. from traffic accidents or incorrect pumping of cyanide solutions.

As a result of those risks an environmental monitoring program was developed to discover and avoid unwanted impacts to the environment.

1.2 Environmental baseline studies

Prior to the mine start a number of environmental baseline studies were performed. The first study was on the Arctic char population in the Kirkespir River in 1988 (Boje 1989). During the exploration phase freshwater samples from the Kirkespir River were analyzed for metals and general parameters (Lakefield 1998a, b, 1999a-d). In comprehensive baseline studies performed during 1998-2001 fish, mussels, seaweed, snow crab, sea urchin, benthic macro fauna and sediments were collected and analyzed for different metals (Glahder et al. 2005). The above and other studies were included in the Environmental Impact Assessment by SRK Consulting (2002). Based on the above mentioned studies and the mining methods and current procedures, the monitoring program presented below was designed.

Photo 1.1. Nalunaq camp and the Kirkespir mountain (upper right) seen from the road to the mine entrance (photo by L Bach).

1.3 Monitoring program

Requirements for monitoring of the environment in relation to the mining activity were set by the Mineral Resources Authority (MRA) of the Greenland Government. These requirements are described in the MRA exploitation license of 19 March 2010, Phase 6, §§19/43, chapter 8.

2 Methods

2.1 Cyanide monitoring program

Due to the mining activities and the use of the CIP method involving cyanide, an intensive monitoring program for detection of cyanide in the environment was conducted. The mining company was responsible for conducting the monitoring program (i.e. sampling and sample analyses) and forwarded the data on a regular basis to MRA.

The cyanide monitoring program consisted of frequent (see Table 2.1) collection of water samples for analysis for cyanide. One process water sample was taken inside the mining area and 5 environmental samples were taken outside in the environment to ensure that cyanide concentrations in the environment did not exceed the limits set by MRA (identical to the Ontario Province Quality Objectives). To protect organisms and in particular the resident Arctic char from toxic effects the cyanide concentration in the Kirkespir River must not exceed 0.005 ppm (mg/l, measured as WAD cyan, Week Acid Dissociable cyanide).

2.1.1 Collection of samples

Water samples were collected at 6 different sampling stations. Sample 1, 2 and 3 were collected and analyzed daily, while sample and analyses of sample 4, 5 and 6 were performed weekly (figure 2.1 and table 2.1).

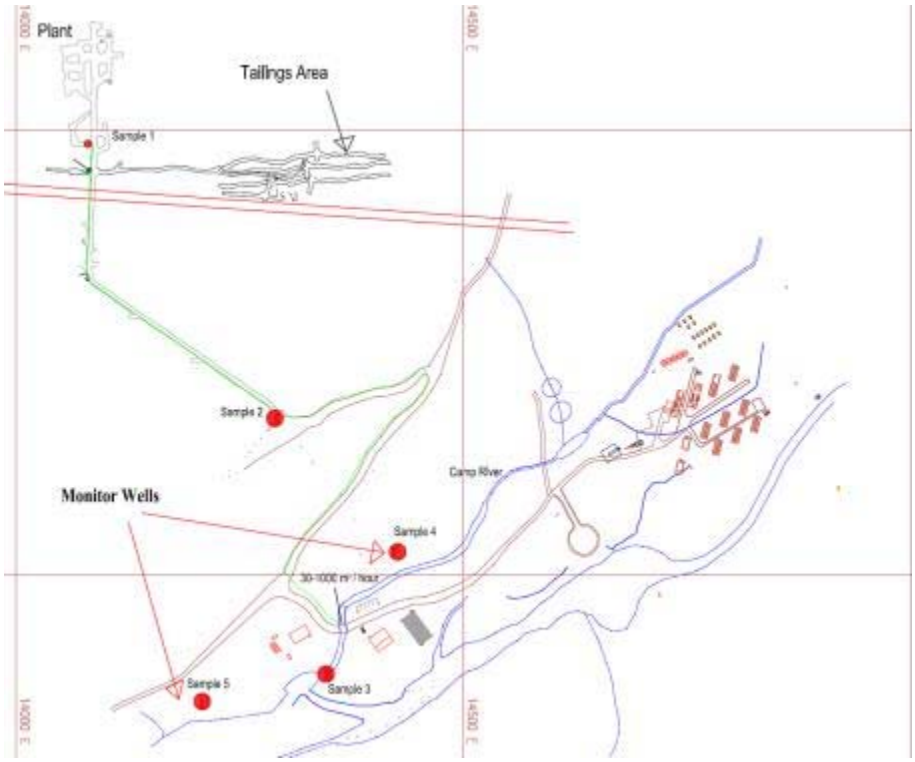

Figure 2.1. Sampling stations for cyanide monitoring. Sample 1 was taken from the tailings water, sample 2 was taken at the 300 m mine entrance, where wastewater is discharged. Sample 3 was taken at the sediment pond and sample 4 and 5 from monitoring wells. Sample 6 was taken further down the Kirkespir River and is not shown in the map.

Table 2.1. Cyanide sampling program and allowed maximum limit values in ppm (parts per million or mg/l).* Monthly averages with maximum allowed value of 10.0 ppm of single samples.

Sampling Station	Location	Monitoring frequency	Maximum cyanide concentration
1	Process water/tailing water	Daily	4.0 ppm in winter* / 2.0 ppm in summer*
2	Wastewater discharge from mine process area/ditch	Daily	0.20 ppm
3	Settlement pond	Daily	0.20 ppm
4	Monitoring well a	Weekly	0.005 ppm
5	Monitoring well b	Weekly	0.005 ppm
6	Kirkespir River - waterfall	Weekly	0.005 ppm

2.1.2 Analyses

Water samples were processed shortly after the sampling at the laboratory facilities in the camp. After filtration the samples were analyzed for cyanide using the Hach-Lange LCK315 method and a Hach-Lange DR2800 instrument. This method is fast and easy and has a factory guaranteed measuring range of 0.01– 0.60 ppm, within which precise results can be obtained. The practical detection limit is judged to be about 0.002 ppm.

Photo 2.1. Shorthorn sculpins are caught at the marine stations and measured and weighted before the liver is dissected out for element analysis (photo by L. Bach).

2.2 Element monitoring program

The element monitoring consists of three compartments: the marine, the freshwater and the terrestrial environment. For the marine environment brown seaweed (*Fucus vesiculosis*), blue mussel (*Mytilus edulis*) and shorthorn sculpin (*Myoxypephalus scopius*) are sampled at stations that are placed relatively close to, and on each side of the Kirkespir River outlet. For the freshwater environment the sampling station is placed at the first site downstream the mining area, where resident Arctic chars (*Salvelinus alpinus*) are occurring. Sampling stations for the terrestrial environment (lichen, *Flavocetraria nivalis*) are placed both in connection with the above mentioned marine stations and around existing and former ore stockpiles around the 300 m portal and along the road.

All samples collected at the stations are specified in Appendix 2.

2.2.1 Collection of samples

Sampling in the Kirkespir Bay and at the north-eastern point of Amitsoq Island (AMIT) was performed with a motor boat. Sampling of blue mussels and seaweed was performed at low tides (Danish Maritime Safety Administration 2011).

Mussels were collected at five stations M1-M5 and AMIT and in two size groups for each station (see Appendix 3). Each sample consisted of approximately 20 individuals. The mussels were opened and allowed to drain, the soft parts cut free and frozen in plastic bags for later element analysis.

Seaweed was collected at two spots within an area of approximately 20 m at each station resulting in two samples per station. The growth tips of seaweed from this year were cut off, washed in freshwater, and frozen in plastic bags. Stations were identical to the blue mussel stations M1-M5 and AMIT.

Shorthorn sculpins were jigged from motor boat at the stations U1, U3, U4 and AMIT. Sculpins at U2 were caught from the barge at the pier. In total 26 shorthorn sculpins were caught. All sculpins were measured and weighed and the livers were taken out and frozen in plastic bags.

Sediment and water samples were collected in the Kirkespir River and water was filtered to 0.45 µm at site immediately after sampling.

Resident Arctic chars were caught in the Kirkespir River at the waterfall pond. This population consists of both non-migrating and migrating chars and if possible non-migrating chars are preferred. Resident Arctic chars stay all their life in the Kirkespir River, whereas the migratory form leaves the river during May and returns around August to spawn and winter. This year 5 migrating chars were sampled. In the camp each fish was measured, weighed and the liver was dissected out.

Lichens were sampled at 24 stations: Nine stations in the Kirkespir Valley downstream the camp, two stations in the camp area, three stations north of the camp, five stations in the Kirkespir Bay area and one station in the north-eastern part of Amitsoq Island (station AMIT) (figure 2.2). Lichens at station 1 and 2 were not sampled due to logistic problems. Lichens sampled at AMIT were transplanted to t-stations M2-t, 5-t, 6-t, 11-t, 12-t, 20-t, 21-t, 22-t, 23-t and 24-t after transplanted lichens from 2012 were sampled and the sta-

tions cleaned. The transplantation of lichens from an unpolluted area into a monitoring area followed by collection sometime after, provide possibility to assess the relative spatial and temporal variations in dust deposition of metals. The application of transplanted lichens, as opposed to resident lichens, have the advantage that the exposure time of the lichens is known and any change in the lichen metal composition relative to the original composition can be related to that site and period (Søndergaard et al., 2013).

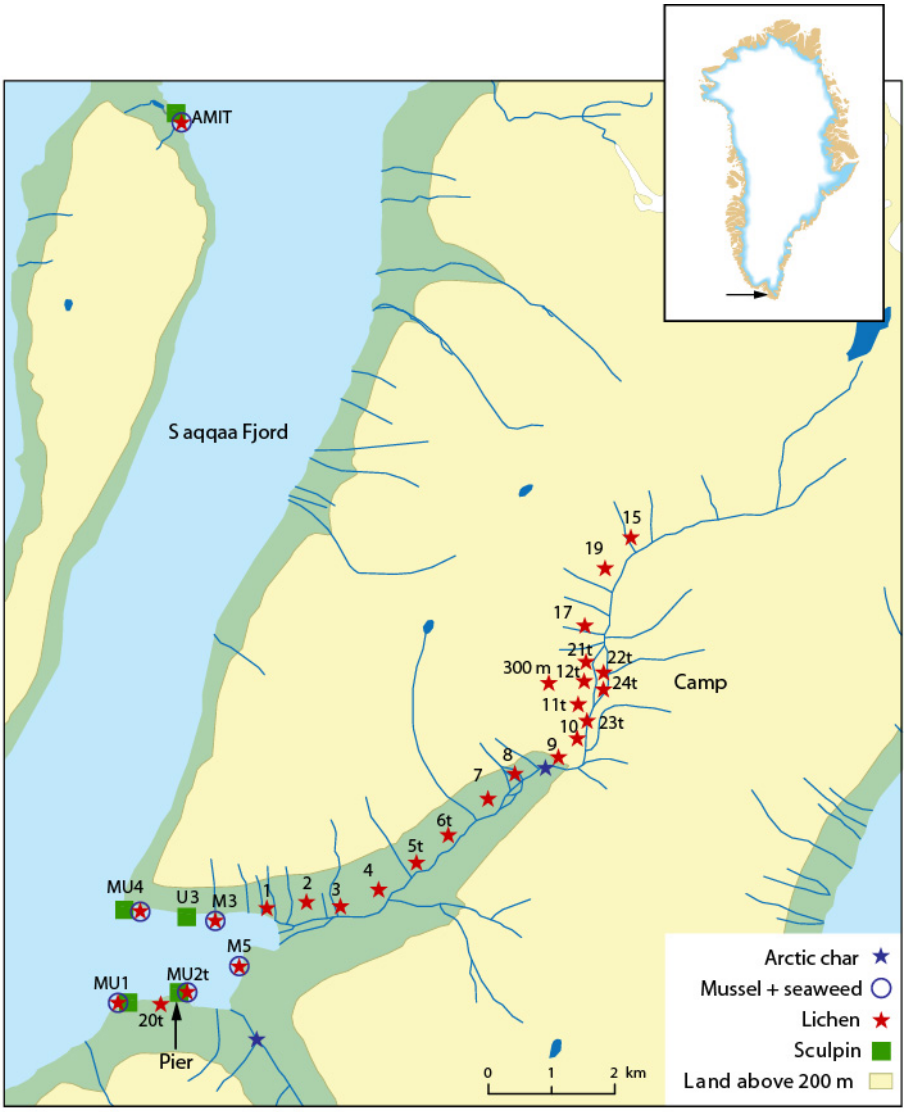

Figure 2.2. Sampling stations in the Nalunaq Gold Mine area, Nanortalik, South Greenland. M: Marine stations: Blue mussel and brown seaweed. U: Shorthorn sculpin stations. Arctic chars were caught near the lichen station 9 at the waterfall station. Lichens were sampled at 24 stations (station 1 and 2 were left out due to logistic matters). Lichens transplanted in 2012 from AMIT were sampled at stations M2-t, 5-t, 6-t, 11-t, 12-t, 20-t, 21-t, 22-t, 23-t and 24-t replaced with new lichens from AMIT. The mine entrance is west of the camp area.

2.2.2 Analyses

All samples were transported frozen directly to DCE-Danish Centre for Environment and Energy. A total of 95 samples of blue mussel (13), brown seaweed (12), livers of shorthorn sculpin (26), freshwater (5), sediments (5), livers of Arctic char (10) and lichens (24) were analyzed for the following 12 metals: arsenic (As), gold (Au), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), mercury (Hg), nickel (Ni), lead (Pb), selenium (Se) and zinc (Zn).

Chemical analyses

Following freeze drying at DCE subsamples of 0.3-1.0 g were digested in half-concentrated Suprapure nitric acid under pressure in Teflon bombs in a microwave oven. The samples where then diluted to ca. 25 grams with Milli-

Q water and all metals were analyzed by ICP-MS (Inductively Coupled Plasma Mass Spectrometry), an accredited method according to DANAK, accreditation No. 411). Hg and Co are not included in this accreditation. All chemical results are listed in Appendix 4. Simultaneously with the Nalunaq samples, blind samples, duplicates and certified reference materials (Dorm-3, Dolt-4 and Tort-2) were analyzed as part of the laboratory quality control. In appendix 1 the analytical results of the certified reference materials are compared to the certificate values. As shown, the analytical results are close to the certificate values.

The filtered water samples were stabilized with 2 g/l nitric acid and then analyzed by ICP-MS.

2.2.3 Data analyses

Data obtained in this monitoring program (2013) was compared with data obtained in the baseline studies (data from 2000-2002; Glahder et al. 2005)) that were conducted before the gold mining started in the area. Further, the monitoring stations were compared to the reference station, AMIT, which is situated 15 km away from the mining area and is assumed not to be affected by mining activities. Results gained in the previous monitoring programmes (Bach and Asmund 2013; Bach et al. 2012; Glahder and Asmund 2005, 2006, 2007; Glahder et al. 2008, 2009, 2010) are also included in the analyses for comparisons.

Differences in element concentrations in brown seaweed, mussels, shorthorn sculpins and Arctic chars were tested using one-way analysis of variance (ANOVA) after logarithmic (base e) transformation of all data to meet the assumption of normal distribution and variance homogeneity. Post hoc Tukey's studentized range tests were applied to test for differences between sites and background. The level of statistical significance used was $p < 0.05$.

We tested separately the stockpile of crushed waste rock and the camp area for differences in concentrations of Cu, Cr, As and Co in lichens in the years 2004-2013 compared to background concentrations using the same statistical method as described above. Finally, the relations between concentrations of Cu, Cr, As and Co in lichens and the distance to the gravel road and the crusher were analyzed with linear regression analyses using logarithmic transformed element concentrations as dependent variable and logarithmic transformed distance as independent variable.

3 Results and discussion

3.1 Cyanide monitoring program

Cyanide concentrations are measured in water samples collected in the freshwater system around the mine area and in the Kirkespir River. Water sample data has been forwarded to MRA 1-2 times a week and evaluated. Cyanide concentrations in the samples are considered elevated if the values exceed the maximum concentration limit according to Table 2.1 except for station 1, where the values given in the table are the monthly average values that must not be exceeded.

Continuous control of cyanide concentrations in process water, wastewater and in recipients was exercised to avoid risk of adverse effects on the environment. The cyanide concentrations appeared rather stable during most of 2013 and the monthly average values were below the maximum limit concentrations set by the MRA. In March, however, high concentrations of cyanide were measured in sample 1 and 2 over some days, resulting in one high measurement in the settlement pond. The plant was shut down, cleaned for all cyanide and restarted again to get the cyanide concentrations down to acceptable level. It is our impression that due to the fast response by the company and due to the existence of the settlement pond to absorb peak concentrations, no harm was done to the Kirkespir River.

In August DCE inspected the cyanide analytical program with satisfactory results.

During winter the company experienced difficulties in taking the samples 3, 4, 5 and 6 in a safe and secure way due to high snow levels, resulting in increased risk that concentrations above maximum allowed concentrations would not be detected.

During the closure of the mine in November, the ditch was redirected to the tailings area, so all water was then running down to the tailings area. DCE followed the closure closely, inspected the process and took water samples for cyanide analyses from all water bodies left inside the mine. The samples were analyzed on site. All water samples from water bodies left in the mine after closure contained cyanide in concentrations under the level of toxicity.

Conclusions on the cyanide monitoring program

In general, the measured cyanide concentrations have been kept at a stable and low level as expected, except for the incident in March 2013. There was continuous control of the discharge to the freshwater environment with frequent monitoring.

Photo 3.1. All waste water from camp and from the mine is lead through the settlement pond for sedimentation of particles and increase the retention time of the water (photo by L Bach).

There was no cyanide pollution detected in the Kirkespir River while the mine was in operation and while daily control was conducted (no concentrations above water quality criteria) and it is expected that there will be no cyanide pollution in the Kirkespir River in the future. DCE will conduct environmental monitoring in Nalunaq for at least three years after closure (2014, 2015 and 2016) and the monitoring will include samples of water from Kirkespir River, monitoring wells, settlement pond and other relevant water bodies. Samples will be analyzed for cyanide to confirm that cyanide does not pollute the environment from unexpected sources.

3.2 Element monitoring program

Element concentrations were obtained from biota sampled in the marine environment in the Kirkespir Bay, in the freshwater environment in the Kirkespir River and in the terrestrial environment of the Kirkespir Valley (figure 2.2). The analytical results and detection limits, as well as background concentrations (Glahder et al. 2005) are given in Appendix 4. Element concentrations in the species analyzed are considered elevated if they are significantly ($p< 0.05$) higher than the background concentrations.

3.2.1 The marine environment

Samples from the Kirkespir Bay were collected at five mussel and seaweed stations (M1-M5), at four sculpin stations (U1-U4) and at the reference station (AMIT) (figure 2.2).

In mussels, Cr and Co were found in significantly elevated concentrations at M3 and Fe at M1, M3, M4 and M5 compared to the reference station (AMIT) and/or background measurements (one-way ANOVA). At all stations the concentrations of Au were up to seven times higher than the concentration at the back-ground station AMIT, with the highest concentration found at station M3.

In brown seaweed, significant, but small, elevated average concentrations were found at station M2 and M3 for As and at station M2, M3 and M5 for Co compared to AMIT and to background concentrations (data from 2000, one-way ANOVA). At all stations the Cu concentrations were markedly higher than background concentrations and higher than concentrations at AMIT, with concentrations at M3 and M5 being 10 times higher than back-ground concentrations. The Cu concentrations were not higher than those from 2011 and 2012. Further, significantly elevated concentrations of Co were found at station M3, M4 and M5 compared to background concentrations. Significantly higher values were found for Au at all stations compared to AMIT. No elevated concentrations of other metals analyzed were found at any of the other seaweed stations (Appendix 4).

Photo 3.2. An intensive monitoring program was conducted to protect the Arctic chars of the Kirkespir River from cyanide and metal exposure. Fish are being caught in Krikespir River, and analysed for metals (photo by L. Bach).

In sculpin liver, no element concentrations were significantly elevated compared to the background concentrations (data from 2000).

Conclusions on the marine environment

In terms of elevated metal concentrations the impact from the mining activities was found to be confined to the area close to the Kirkespir River outflow, as in previous years.

Few metals (Au, Co, Cr and Cu) were found in elevated concentrations in mussel and seaweed samples and the impact was only found at the stations closest to the estuary and no elevated concentrations were found in sculpins.

In general, during the past seven years (2006-2013), the discharge of metals to the marine environment has been low and the impact from the mining industry is considered low.

3.2.2 The freshwater environment

In livers from migrating Arctic char in Kirkespir River no element concentrations were found to be significantly different from the background data (data from 2000) (Appendix 4). Arctic chars were also caught upstream in the area shortly after the camps sewage treatment plant. These chars were of non-migrating small specimens. This is the first year that a larger stock of fish has been observed in this area. These chars had higher concentrations (2-4 times) of As, Au, Fe and Se than migrating fish from the Waterfall station in Kirkespir River, which most likely is related to their stationary way of life and the natural high occurrence of these elements in the area.

Water and sediment samples were also taken in the Kirkespir River. Samples were taken in the water and sediment upstream the mine, at the outflow of process water, in the settlement pond and below the waterfall. It is obvious that the discharge of wastewater from the process adds metals to the river water and sediment. Concentrations above MRA guidelines of especially As and Cu, but also Au, Co, Fe, Ni and Se, were measured in the discharged wastewater and in the settlement pond. The settlement pond seems very efficient and when the water is leaving the settlement pond the element concentrations have decreased to levels similar to upstream concentrations. Measurements of both sediment and water at the Waterfall station show low levels for all metals, and the water concentrations are below the Greenland Water Quality Guidelines (MRA Guidelines, 2011).

Conclusions on the freshwater environment

Elevated concentrations of several metals, especially As and Cu, were found in the discharged wastewater from the mine. The settlement pond seems, however, to work efficiently and retains a large fraction of the metals. No elevated concentrations were measured downstream in the Kirkespir Valley and no elevated element concentrations were found in Arctic char in the Kirkespir River at the Waterfall station compared to background concentrations for the area. In general, the mine causes only little impact on the freshwater environment and as the outflow of wastewater from the mine has stopped with the closure of the mine, no impact is expected in the future.

3.2.3 The terrestrial environment

Concentrations of four metals (Cu, Cr, As and Co) in lichens were compared between years from 2004 to 2013. Three areas (see figure 2.2. for station

numbers) were selected, the stockpile of crushed waste rock (stations 5 and 6), the camp and mine area (stations 11 and 12) and the area around the pier, which previously worked as a stock pile area (stations M2 and 20). In 2012, as in previous years, lichens were transplanted from an uncontaminated area (station AMIT) to these six stations: M2-t, 5-t, 6-t, 11-t, 12-t, 20-t, 21-t, 22-t, 23-t and 24-t. In 2013 these transplanted lichens were analyzed together with lichens growing naturally in the Kirkespir Valley.

The temporal trends in concentrations of the four metals were compared in the three areas described above. The results are shown in figure 3.1 (Area 1), figure 3.2 (Area 2) and figure 3.3 (Area 3). Concentrations of all four metals in Area 1, which are station 5-t and 6-t, have been decreasing since 2009. This area was previously used for a stockpile of waste rock. In Area 2, which is the area around the camp and downhill the mine (station 11-t and 12-t) the concentrations of the four metal seemed stable until 2010, but peaked slightly in 2011 probably due to the restart of the mining activities. Since then the concentrations have been decreasing.

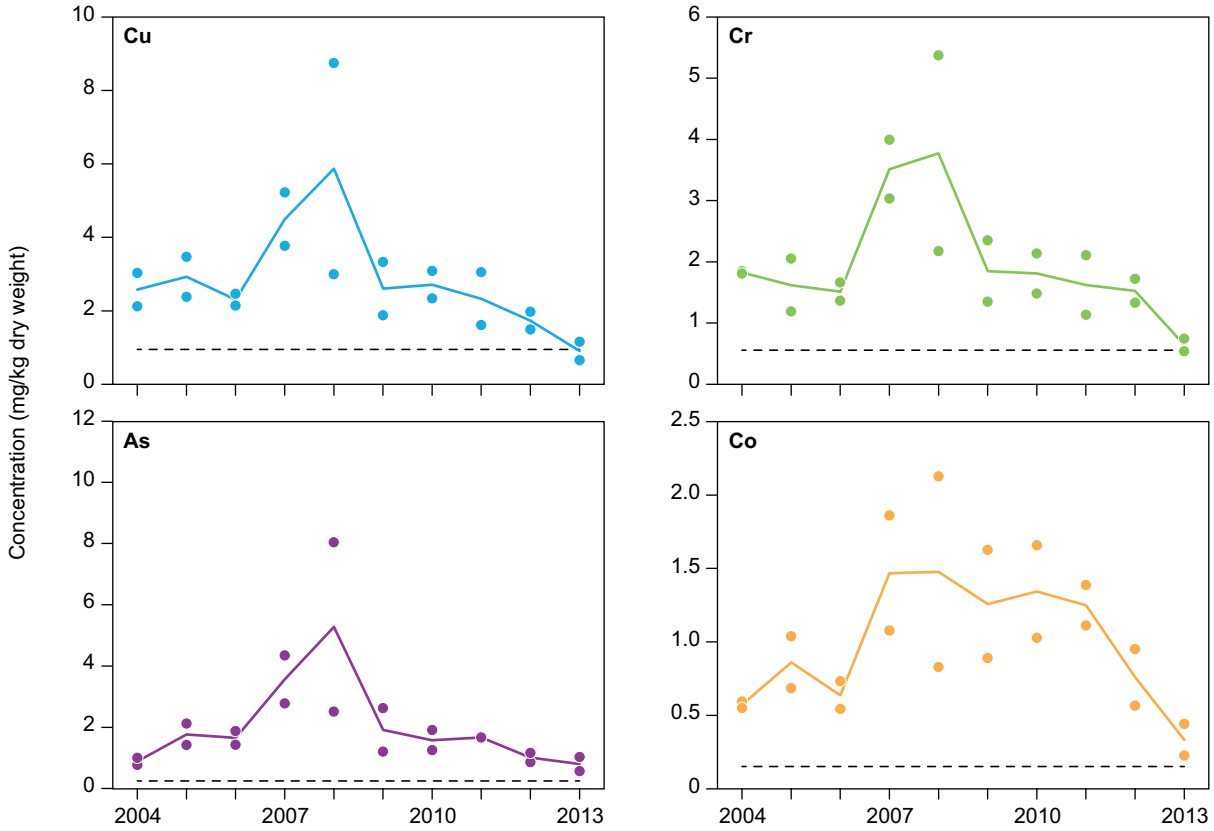

Figure 3.1. Temporal trends in concentrations of Cu, Cr, As and Co in lichens from Area 1 during 2004-2013. Area 1 is the stockpile of crushed waste rock (stations 5-t and 6-t). From 2008 onwards concentrations are from transplanted lichens. Baseline average concentrations from 1998 are shown as dashed lines.

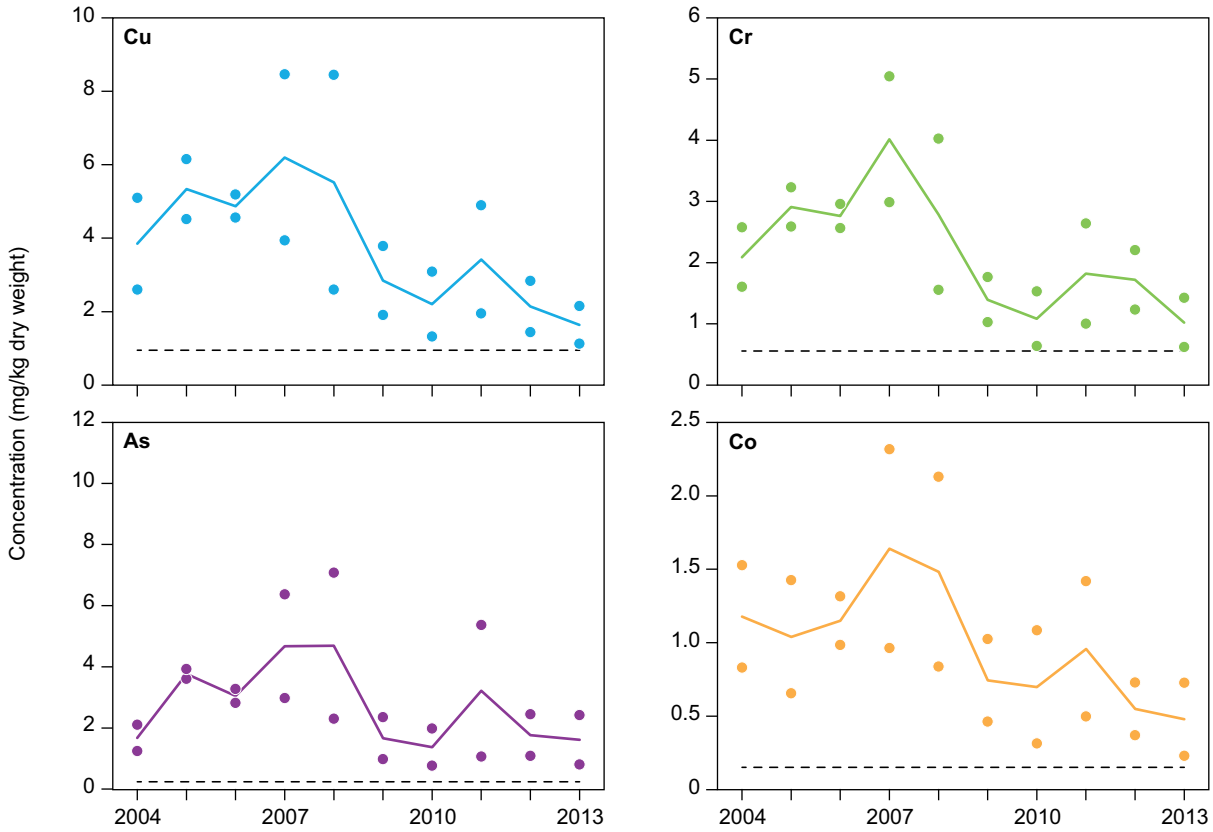

Figure 3.2. Temporal trends in concentrations of Cu, Cr, As and Co in lichens from Area 2 during 2004-2013. Area 2 is the camp and mine area (stations 11-t and 12-t). From 2008 onwards concentrations are from transplanted lichens. Baseline average concentrations from 1998 are shown as dashed lines.

Average concentrations in each of the three areas were compared with background concentrations and while Cu, Cr, As and Co have been significantly elevated in the years 2004-2012, only As was found in significantly elevated concentrations in area 2 in 2013 (Tukey's post hoc test). In 2013, the concentrations of the four metals were decreasing (though not all significant) compared to 2012 and the concentrations of Cu in area 1 and 3, and Cr and Co in area 3 were below the baseline concentrations (data from 1998).

A third area of particular interest is the area around the pier, the former stockpile area (Area 3). During the last mining period, large stockpiles of ore were placed in the field above the pier, intended for shipping off. As the Crew mine closed in 2009, a stockpile was left and the ore was transported back to the mining area for processing between 2011 and 2012. Concentrations of the four metals in the pier area (station 20-t and M2-t) in 2011 were found to be 2-29 times higher than the background concentrations, but in 2013 only As was found in concentrations higher than baseline concentrations (data from 1998). These results indicate that the metal dust pollution can be temporary and directly related to activities.

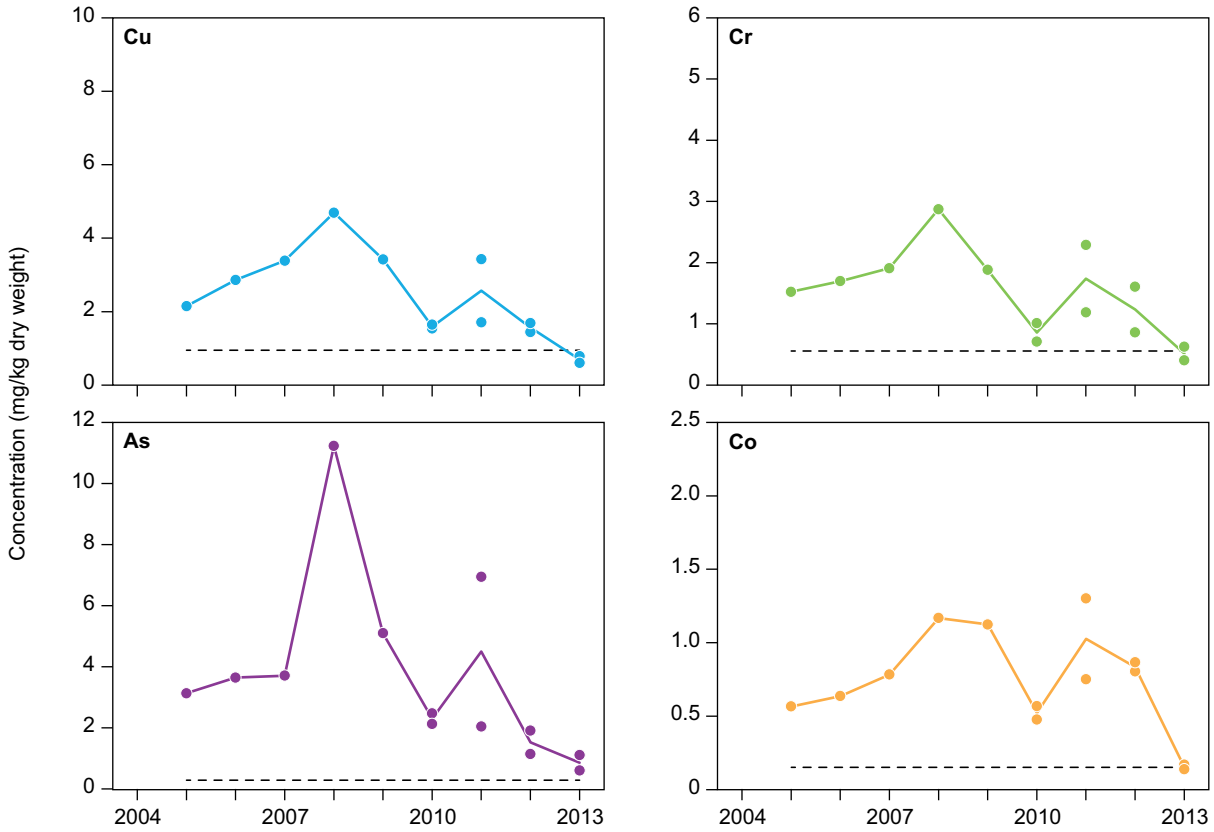

Figure 3.3. Temporal trends in concentrations of Cu, Cr, As and Co in lichens from Area 3 during 2004-2013. Area 3 is the area around the pier (stations M2 and 20-t). From 2008 onwards concentrations are from transplanted lichens. Baseline average concentrations from 1998 are shown as dashed lines.

Relations between the concentrations of Cu, Cr, As and Co in lichens and the perpendicular distance to the gravel road and to the 300 m portal area were tested. Previous results have shown effects of the gravel roads, and as the company has been allowed to perform crushing outdoor at the 300 m portal where also waste rock is deposited, the 300 m portal was also included in the analysis.

All concentrations of the four metals showed a significant increase with decreasing distance to the gravel road (log linear regression). Figure 3.4a shows concentrations of the four metals in lichens from Amitsoq Island (AMIT), the Kirkespir Bay area and the Kirkespir Valley. Three areas have higher concentrations of the four metals, namely the pier area, the inner valley area counting the stockpile of waste rock, and the mining/camp area. The higher concentrations in these areas can be explained as an effect of the short distance to the gravel road illustrated by figure 3.4b. Before 2009, the higher concentrations in the mining/camp area were explained as an effect of the mine rather than an effect of the road (Glahder et al. 2010). In 2010, a marked decrease in the concentrations of all four metals was seen at the pier area compared to concentrations found in 2009. This indicated, that the road was the main source of contamination after the storage in the pier area and the ship-loading activities had ceased. At the pier area, higher concentrations of the metals were found in 2011 due to loading and transporting ore from the pier area back to the mine for processing. This activity only took place in 2011, and in 2012 a decrease was observed for all four metals at the pier area. In 2013, the metal concentrations in the area have even decreased further and are now similar to baseline concentrations. In 2011 an increase in

all four metals at station 11 in the mining area compared to the metal concentrations in 2010 was found. This indicated that besides the effect of the gravel road, there could also be an effect of the mining in the area, which might be a result of the outdoor crushing at the 300 m level portal. In 2012, further lichen stations were added to the monitoring program to investigate the proposed effect of outdoor crushing. Data gained in 2013 reveals however a much less pronounced effect of the 300 m level portal than the effect of the gravel road (figure 3.4a and b).

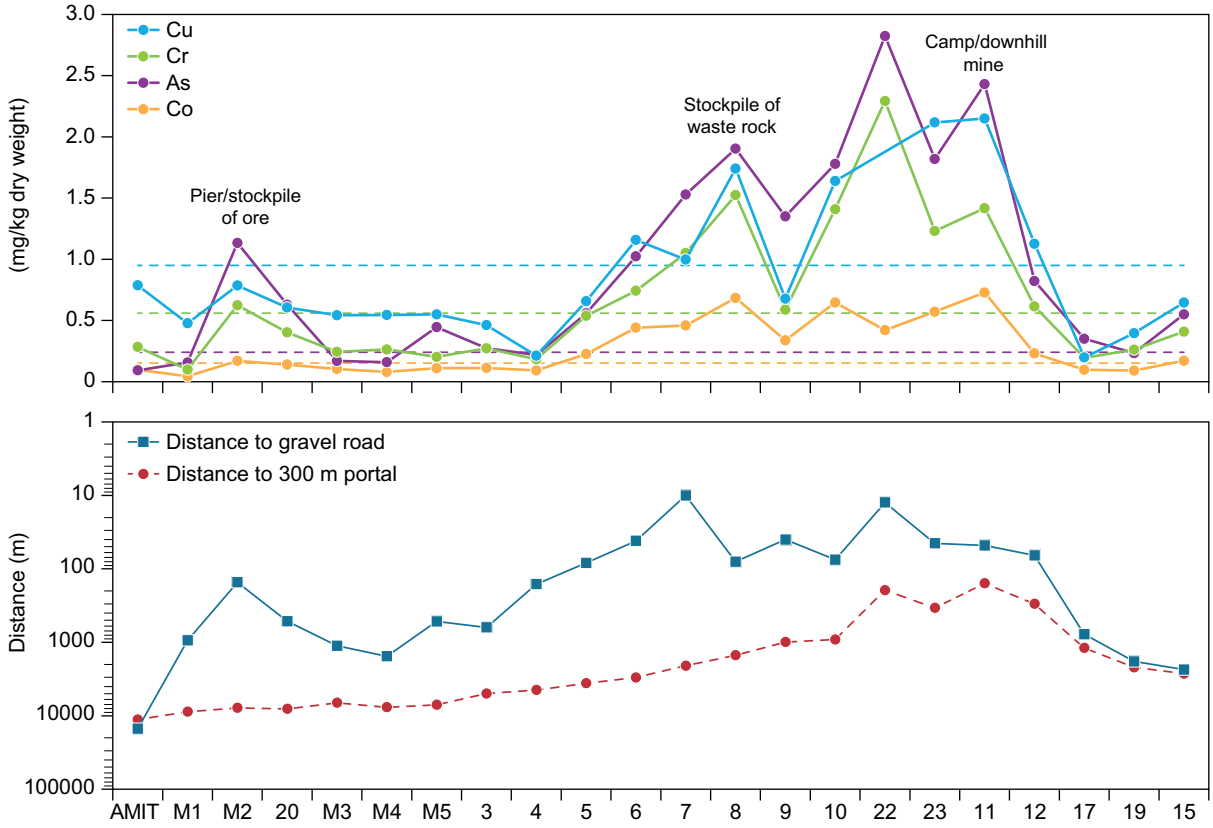

Figure 3.4. a) Concentrations of Cu, Cr, As and Co in the lichen *Flavocetraria nivalis* measured at the lichens stations in 2013 and b) distances (in meter on a log scale) from the lichen stations to the road and to the 300 m portal. For localization of lichen stations see figure 2.1. M1-M5 are stations in the Kirkespir Bay area, stations 3-24 are situated in the Kirkespir Valley from the coast (station 3) to up-stream the camp area. The dashed horizontal lines in a) indicate average background concentrations of the four metals (see Appendix 4).

Figure 3.5 shows how far from the road elevated concentrations of Cu, Cr, As and Co were found in the Kirkespir Valley in 2013. For As background concentrations were met about 1500 m from the road, whereas Co and Cr reached background levels at distances of 400 and 140 m, respectively, and Cu at about 80 m from the road.

Figure 3.5. Concentrations of Cu, Cr, As and Co in the lichens *Flavocetraria nivalis* as a function of the stations' distances to the gravel road (in meters - on a log scale). Background average concentrations are shown with horizontal dashed lines.

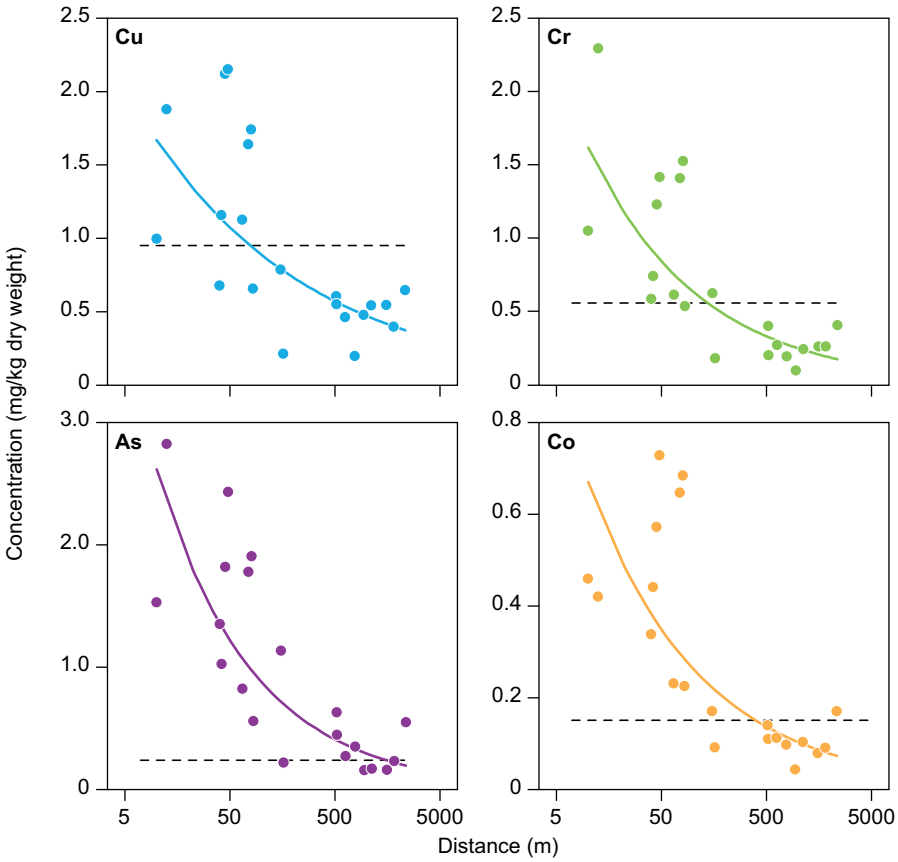

Photo 3.3. Lichens (*Flavocetraria nivalis*) transplanted early September 2012 in the Kirkespir Valley were sampled early September 2013. Transplanted lichens were covered by a net secured by stones. Lichens sampled at Amitsoq Island (reference site) in 2013 replaced the sampled lichens (photo L. Bach).

Conclusions on the terrestrial environment

Concentrations of Cu, Cr, As and Co in lichens during 2004-2012 were significantly elevated at the pier area, the waste rock stockpile and in the mine area compared to the background levels, with peak concentrations in 2008. Concentrations of all four metals in all three areas decreased toward 2010, but due to new activities the dust pollution increased again in 2011. In 2013, the concentrations had however decreased again and only As was still found significantly elevated in area 2.

The previous findings of high concentrations in the three areas can be explained as an effect of the gravel road with an exception of the most impacted stations (11-t and 20-t), where mining activities may be the main reason. Before 2009, the higher concentrations in the mine area were explained as an effect of the mine. In 2010, a marked decrease in concentrations of all four metals was seen in the pier area, indicating that the road at that time was the main source of contamination. However, in 2011 activities in this area caused increased concentrations again at both the pier and the mining/camp area. The impact in the pier area had decreased in the 2013 sampling program, as the activities related to loading of trucks at the pier area have been completed.

In general, the impact on the terrestrial environment is decreasing, and the levels are expected to decrease to baseline levels within the next 3 years. After the closure of the mine in November 2013, only limited effects on the terrestrial environment is expected. Possible impacts are then expected to be due to 1) dust dispersal from the waste rock that is deposited on the mountain side, which is expected to be minor; 2) transportation of material from camp and mine to the harbor during clean-up of the mine due to dust dispersal from road material, and 3) dust dispersal during restoration of the landscape.

4 Conclusions

This report describes the results of the tenth year of environmental monitoring in the Nalunaq Gold Mine area and describes the third year of the cyanide monitoring program. Most mining work from August 2009 until spring 2011 dealt with the excavation of a chamber inside the mine and the building of a production plant. In spring 2011, the mining and processing of ore was initiated, and parts of the low grade ore were transported from the pier back to the mine for processing. From then on, the mining and processing of ore took place inside the process hall in the mountain with some outdoor crushing at the 300 m portal. In November 2013, the mine closed and clean-up of the area was initiated. Full clean-up and restoration of the landscape are expected to be completed during summer 2014.

Concerning the cyanide monitoring program, water samples have been taken frequently during 2013. In March the company experienced problems in the plant and high cyanide concentrations were reported. The company shut down the plant, cleaned it for cyanide and started up again. Hereafter were the cyanide concentrations below maximum acceptable concentrations. This occurrence did not lead to any risk.

The impact from the mining activities on the marine environment was also this year found to be confined to the area close to the outflow from Kirkespir River. Small elevated element concentrations of most metals were, however, found in blue mussels and brown seaweed at the stations closest to the estuary (primarily station M3 and M5). No elevated element concentrations were found in sculpin livers. In general, during the years of 2006-2013 the concentrations of metals in the marine environment have been low and not remarkably different from background levels.

In the river system, highly elevated concentrations of several metals, particularly in As, Au, Co, Cu, Fe, Ni and Se, were measured in the discharged wastewater from the mining process and in the settlement pond. The settlement pond seems very efficient in removing particles, and no elevated concentrations were measured in the Kirkespir River at the Waterfall station. Also, at the Waterfall station no elevated concentrations were found in Arctic char livers.

As previous years, concentrations of Cu, Cr, As and Co in lichens were significantly elevated compared to the background level at the stockpile of crushed waste rock and in the mining/camp area. The concentrations are however decreasing and the concentrations found at the pier area were now only found elevated for As.

Temporal trends during 2004-2013 of the concentrations of As, Co, Cr and Cu in the three areas described above showed a general decrease after 2009 for all metals in all three areas. However, in 2011 a small increase of the metals was observed at the pier and at the camp/mining area, but in 2013 the element concentrations are steadily decreasing and were not higher than in 2010.

Photo 4.1. Brown seaweed samples attracted one of the curious Arctic fox cubs that live around the camp (Photo: L Bach).

The concentrations of Cu, Cr, As and Co in lichens were significantly highest close to the gravel road. Concentrations of As above the background level could be found until a distance of about 1500 m from the road, while concentrations of Co, Cr and Cu met the baseline level about 400, 140 and 80 m from the road, respectively.

Overall

In 2013, the impact from the gold mine on the local environment was primarily observed in the Kirkespir Valley originating mainly from dust dispersed from the road and from the crushing area at the 300 m portal of the mine, and from the loading of ore at the area above the pier. Element concentrations in lichens increased a little in 2011 compared to 2010 due to mining activities, but since then the element concentrations decreased and are in 2013 below the concentrations in 2010. In the Kirkespir River and Kirkespir Bay, no elevated concentrations were found in Arctic char or in sculpins and only few elevated concentrations of metals were found in seaweed and mussels.

The environmental impact from spreading of metals in the environment due to mining is considered to be minor and decreasing; and there is no requirement for further actions to reduce the environmental impact.

With the closure of the mine in November 2013, it is expected that the element concentrations in the environment due to the mining activity will decrease even further. A small increase in dust dispersal can be expected, however, during clean-up and restoration of the landscape in 2013/2014. Environmental monitoring will continue in 2014, 2015 and 2016.

5 Acknowledgements

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Appendix 1. ICP-MS analytical results of certified reference materials

Concentrations are given in mg/kg dw (dry weight)

	As	Au	Cd	Co	Cr	Cu	Fe	Hg	Ni	Pb	Se	Zn
Biota-d.l.	*0.024*	*0.001*	*0.006*	*0.004*	*0.034*	*0.296*	*2.7*	*0.015*	*0.059*	*0.018*	*0.104*	*0.13*
Dorm-4	7.68	-0.002	0.330	0.256	3.242	15.76	377.5	0.309	1.361	0.359	3.774	53.66
Dorm-4	6.62	0.003	0.321	0.253	1.925	15.53	387.0	0.372	1.443	0.396	3.658	48.40
Dorm-4	6.30	0.006	0.299	0.254	1.998	15.36	376.1	0.372	1.220	0.372	3.440	53.31
Average	*6.87*	*0.003*	*0.316*	*0.254*	*2.389*	*15.55*	*380.2*	*0.351*	*1.341*	*0.376*	*3.624*	*51.79*
Cf value	*6.80*	*nd*	*0.306*	*nd*	*1.870*	*15.90*	*341.0*	*0.410*	*1.360*	*0.420*	*3.560*	*52.20*
2 x std dev	*0.64*		*0.015*		*0.160*	*0.90*	*27.0*	*0.055*	*0.220*	*0.053*	*0.340*	*3.20*
Dolt-4	9.70	0.000	25.83	0.238	1.204	33.60	1988.9	2.678	1.695	0.094	9.132	127.9
Dolt-4	8.83	0.002	24.57	0.234	1.273	32.46	1957.0	2.662	1.074	0.116	7.846	116.9
Dolt-4	9.07	0.011	25.24	0.229	1.503	32.27	1910.9	2.676	0.994	0.174	7.939	115.8
Dolt-4	8.97	0.004	25.12	0.235	1.303	32.92	1991.8	2.687	0.980	0.156	8.326	119.1
Average	*9.14*	*0.004*	*25.19*	*0.234*	*1.321*	*32.81*	*1962.1*	*2.676*	*1.186*	*0.135*	*8.311*	*119.9*
Cf value	*9.66*	*nd*	*24.30*	*0.25**	*1.40**	*31.20*	*1833.0*	*2.580*	*0.970*	*0.160*	*8.300*	*116.0*
2 x std dev	*0.62*		*0.80*			*1.10*	*75.0*	*0.220*	*0.110*	*0.040*	*1.300*	*6.0*
Tort-2	21.84	0.010	29.09	0.545	2.002	115.2	175.2	0.297	3.073	5.530	5.663	185.9
Tort-2	23.04	0.037	29.62	0.499	0.734	106.4	118.1	0.277	2.219	0.395	5.202	177.3
Average	*22.44*	*0.023*	*29.36*	*0.522*	*1.368*	*110.8*	*146.7*	*0.287*	*2.646*	*2.963*	*5.433*	*181.6*
Cf value	*21.60*	*nd*	*26.70*	*0.510*	*0.770*	*106.0*	*105.0*	*0.270*	*2.500*	*0.350*	*5.630*	*180.0*
2 x std dev	*1.80*		*0.600*	*0.090*	*0.150*	*10.0*	*13.0*	*0.060*	*0.190*	*0.130*	*0.670*	*6.0*
BCR 482	0.73	0.005	0.553	0.297	2.899	6.68	839.3	0.469	2.371	36.722	0.286	101.8
BCR 482	0.74	0.029	0.581	0.326	3.871	7.40	888.8	0.494	2.552	38.976	0.356	99.8
Average	*0.73*	*0.017*	*0.567*	*0.312*	*3.385*	*7.04*	*864.0*	*0.482*	*2.461*	*37.849*	*0.321*	*100.8*
Cf value	*0.85*	*nd*	*0.560*	*nd*	*4.120*	*7.03*	*nd*	*0.480*	*2.470*	*40.900*	*nd*	*100.6*
2 x std dev	*0.07*		*0.020*		*0.150*	*0.19*		*0.020*	*0.070*	*1.400*		*2.2*
Sediment- d.l.	*12.5*	*0.11*	*0.01*	*0.5*	*2*	*0.8*	*40*	*2.48*	*2.1*	*5.1*	*1.2*	*7.0*
Pacs-2	19.0	-	1.91	10.9	78	289.3	39420	1.41	36.4	168.1	-	360.1
Cf value	*26.20*		*2.11*	*11.5*	*90.700*	*310*	*40900*	*3.04*	*39.50*	*183*	*0.92*	*364*
2 x std dev	*1.5*		*0.15*	*0.3*	*4.6*	*12*	*600*	*0.20*	*2.3*	*8*	*0.22*	*23*
Mess-3	16.6	-	0.19	12.7	97	30.8	40769	-	43.7	20.7	-	198.3
Mess-3	16.0	-	0.16	12.7	94	31.2	40633	-	41.2	19.6	-	160.4
Cf value	*21.20*		*0.24*	*14.4*	*105.0*	*33.9*	*43400*	*0.091*	*46.90*	*21.1*	*0.72*	*159*
2 x std dev	*1.1*		*0.01*	*2*	*4*	*1.6*	*1100*	*0.009*	*2.2*	*0.7*	*0.05*	*8*
Hiss-1	-	-	-	0.4	14	2.2	2449	-	4.8	1.6	-	6.1
Hiss-1	-	-	-	0.3	14	1.4	2561	-	3.4	0.9	-	6.6
Cf value	*0.80*		*0.024*	*0.65*	*30.0*	*2.29*	*2460*	*0.01*	*2.16*	*3.13*	*0.050*	*4.94*
2 x std dev	*0.1*		*0.009*		*6.8*	*0.37*	*90*		*0.29*	*0.40*	*0.007*	*0.79*

*Information value, not a certificate

Appendix 2. Samples and stations

ID-No	Sample type	Latin name	Station	Lat deg	Long deg
49704	Lichen	*Flavocetraria nivalis*	3	60.32639	-44.90278
49705	Lichen	*Flavocetraria nivalis*	4	60.32861	-44.89389
49706	Lichen	*Flavocetraria nivalis*	5-transplanted	60.33247	-44.88003
49707	Lichen	*Flavocetraria nivalis*	6-transplanted	60.33603	-44.87183
49708	Lichen	*Flavocetraria nivalis*	7	60.34222	-44.86028
49709	Lichen	*Flavocetraria nivalis*	8	60.34556	-44.85194
49710	Lichen	*Flavocetraria nivalis*	9	60.34694	-44.83722
49711	Lichen	*Flavocetraria nivalis*	10	60.34750	-44.83278
49712	Lichen	*Flavocetraria nivalis*	11-transplanted	60.35456	-44.83239
49713	Lichen	*Flavocetraria nivalis*	12-transplanted	60.35783	-44.83058
49701	Lichen	*Flavocetraria nivalis*	15	60.37861	-44.81889
49703	Lichen	*Flavocetraria nivalis*	17	60.36639	-44.83111
49702	Lichen	*Flavocetraria nivalis*	19	60.37500	-44.82528
49714	Lichen	*Flavocetraria nivalis*	20-transplanted	60.31308	-44.95283
49745	Lichen	*Flavocetraria nivalis*	21-transplanted	60.35587	-44.83097
49715	Lichen	*Flavocetraria nivalis*	22-transplanted	60.35545	-44.83050
49716	Lichen	*Flavocetraria nivalis*	23-transplanted	60.35303	-44.83108
49717	Lichen	*Flavocetraria nivalis*	24-transplanted	60.35626	-44.82755
49719	Lichen	*Flavocetraria nivalis*	M 1	60.31139	-44.96694
49718	Lichen	*Flavocetraria nivalis*	M 2-transplanted	60.31253	-44.94639
49720	Lichen	*Flavocetraria nivalis*	M 3	60.32472	-44.94681
49721	Lichen	*Flavocetraria nivalis*	M 4	60.32639	-44.93750
49722	Lichen	*Flavocetraria nivalis*	M 5	60.31567	-44.96028
49723	Lichen	*Flavocetraria nivalis*	AMIT	60.43889	-44.95111
49746	Brown seaweed	*Fucus vesiculosus*	M 1	60.31139	-44.96694
49747	Brown seaweed	*Fucus vesiculosus*	M 1	60.31139	-44.96694
49726	Brown seaweed	*Fucus vesiculosus*	M 2	60.31278	-44.94639
49727	Brown seaweed	*Fucus vesiculosus*	M 2	60.31278	-44.94639
49748	Brown seaweed	*Fucus vesiculosus*	M 3	60.32472	-44.93750
49749	Brown seaweed	*Fucus vesiculosus*	M 3	60.32472	-44.93750
49750	Brown seaweed	*Fucus vesiculosus*	M 4	60.32639	-44.96028
49751	Brown seaweed	*Fucus vesiculosus*	M 4	60.32639	-44.96028
49724	Brown seaweed	*Fucus vesiculosus*	M 5	60.31567	-44.93463
49725	Brown seaweed	*Fucus vesiculosus*	M 5	60.31567	-44.93463
49736	Brown seaweed	*Fucus vesiculosus*	AMIT	60.43889	-44.95111
49737	Brown seaweed	*Fucus vesiculosus*	AMIT	60.43889	-44.95111
49765	Shorthorn sculpin	*Myoxocephalus scorpius*	U 1	60.31306	-44.96250
49766	Shorthorn sculpin	*Myoxocephalus scorpius*	U 1	60.31306	-44.96250
49767	Shorthorn sculpin	*Myoxocephalus scorpius*	U 1	60.31306	-44.96250
49768	Shorthorn sculpin	*Myoxocephalus scorpius*	U 1	60.31306	-44.96250
49769	Shorthorn sculpin	*Myoxocephalus scorpius*	U 1	60.31306	-44.96250
49732	Shorthorn sculpin	*Myoxocephalus scorpius*	U 2	60.31250	-44.94611
49733	Shorthorn sculpin	*Myoxocephalus scorpius*	U 2	60.31250	-44.94611
49734	Shorthorn sculpin	*Myoxocephalus scorpius*	U 2	60.31250	-44.94611
49735	Shorthorn sculpin	*Myoxocephalus scorpius*	U 2	60.31250	-44.94611
49779	Shorthorn sculpin	*Myoxocephalus scorpius*	U 2	60.31250	-44.94611
49781	Shorthorn sculpin	*Myoxocephalus scorpius*	U 3	60.32528	-44.94806

ID-No	Sample type	Latin name	Station	Lat deg	Long deg
49770	Shorthorn sculpin	*Myoxocephalus scorpius*	U 3	60.32528	-44.94806
49771	Shorthorn sculpin	*Myoxocephalus scorpius*	U 3	60.32528	-44.94806
49772	Shorthorn sculpin	*Myoxocephalus scorpius*	U 3	60.32528	-44.94806
49780	Shorthorn sculpin	*Myoxocephalus scorpius*	U 3	60.32528	-44.94806
49778	Shorthorn sculpin	*Myoxocephalus scorpius*	U 3	60.32528	-44.94806
49764	Shorthorn sculpin	*Myoxocephalus scorpius*	U 4	60.32611	-44.95861
49782	Shorthorn sculpin	*Myoxocephalus scorpius*	U 4	60.32611	-44.95861
49783	Shorthorn sculpin	*Myoxocephalus scorpius*	U 4	60.32611	-44.95861
49784	Shorthorn sculpin	*Myoxocephalus scorpius*	U 4	60.32611	-44.95861
49785	Shorthorn sculpin	*Myoxocephalus scorpius*	U 4	60.32611	-44.95861
49740	Shorthorn sculpin	*Myoxocephalus scorpius*	AMIT	60.43889	-44.95111
49741	Shorthorn sculpin	*Myoxocephalus scorpius*	AMIT	60.43889	-44.95111
49742	Shorthorn sculpin	*Myoxocephalus scorpius*	AMIT	60.43889	-44.95111
49743	Shorthorn sculpin	*Myoxocephalus scorpius*	AMIT	60.43889	-44.95111
49744	Shorthorn sculpin	*Myoxocephalus scorpius*	AMIT	60.43889	-44.95111
49752	Blue mussel	*Mytilus edulis*	M 1	60.31139	-44.96694
49753	Blue mussel	*Mytilus edulis*	M 1	60.31139	-44.96694
49730	Blue mussel	*Mytilus edulis*	M 2	60.31278	-44.94639
49731	Blue mussel	*Mytilus edulis*	M 2	60.31278	-44.94639
49754	Blue mussel	*Mytilus edulis*	M 3	60.32472	-44.93750
49755	Blue mussel	*Mytilus edulis*	M 3	60.32472	-44.93750
49773	Blue mussel	*Mytilus edulis*	M 3	60.32472	-44.93750
49756	Blue mussel	*Mytilus edulis*	M 4	60.32639	-44.96028
49757	Blue mussel	*Mytilus edulis*	M 4	60.32639	-44.96028
49728	Blue mussel	*Mytilus edulis*	M 5	60.31567	-44.93463
49729	Blue mussel	*Mytilus edulis*	M 5	60.31567	-44.93463
49738	Blue mussel	*Mytilus edulis*	AMIT	60.43889	-44.95111
49739	Blue mussel	*Mytilus edulis*	AMIT	60.43889	-44.95111
49758	Arctic char	*Salvelinus alpinus*	Waterfall	60.34642	-44.84225
49759	Arctic char	*Salvelinus alpinus*	Waterfall	60.34642	-44.84225
49760	Arctic char	*Salvelinus alpinus*	Waterfall	60.34642	-44.84225
49761	Arctic char	*Salvelinus alpinus*	Waterfall	60.34642	-44.84225
49762	Arctic char	*Salvelinus alpinus*	Waterfall	60.34642	-44.84225
49763	Arctic char	*Salvelinus alpinus*	Waterfall	60.34642	-44.84225
49774	Arctic char	*Salvelinus alpinus*	Upstream		
49775	Arctic char	*Salvelinus alpinus*	Upstream		
49776	Arctic char	*Salvelinus alpinus*	Upstream		
49777	Arctic char	*Salvelinus alpinus*	Upstream		
49792	Water		W 1 Upstream	60.35680	-44.82680
49794	Water		W 2 Outflow mine	60.35573	-44.83399
49795	Water		W 3 In sed. pond	60.35626	-44.82755
49791	Water		W 4 Out sed. pond	60.35626	-44.82755
49793	Water		W 5 Waterfall	60.34642	-44.84225
49786	Sediment		S 1 Upstream	60.35680	-44.82680
49787	Sediment		S 2 Outflow mine	60.35573	-44.83399
49788	Sediment		S 3 In sed. pond	60.35626	-44.82755
49789	Sediment		S 4 Out sed. pond	60.35626	-44.82755
49790	Sediment		S 5 Waterfall	60.34642	-44.84225

Appendix 3. Blue mussel samples

Station	ID NO	No of mussels	Min length (mm)	Max length (mm)
M1	49752	11	7.0	7.9
M1	49753	10	5.3	6.9
M2	49730	15	5.1	6.9
M2	49731	15	7.0	9.2
M3	49754	16	7.0	8.9
M3	49755	14	6.0	6.9
M3	49773	14	5.1	5.9
M4	49756	20	5.0	5.9
M4	49757	13	6.1	6.7
M5	49728	19	6.0	6.8
M5	49729	19	7.1	8.0
AMIT	49738	19	5.0	5.9
AMIT	49739	17	6.0	6.8

Appendix 4. Chemical analyses

Concentrations are given in mg/kg dw (dry weight) for mussels, seaweed, sediment and lichen and mg/kg ww (wet weight) for livers from sculpins and Arctic chars. Detection limits (dl) are given as well as average background concentrations and standard deviations (*SD*) for each species.

ID No		Station	As	Au	Cd	Co	Cr	Cu	Fe	Hg	Ni	Pb	Se	Zn
Blue Mussels – Mytilus edulis (mg/kg)														
Detection limits			*0.024*	*0.001*	*0.006*	*0.004*	*0.034*	*0.296*	*2.72*	*0.015*	*0.059*	*0.018*	*0.104*	*0.130*
49752		M1	11.27	0.187	3.68	0.304	0.643	5.54	184.3	0.063	1.17	0.588	3.07	59.4
49753		M1	12.53	0.164	4.26	0.313	0.803	5.74	228.1	0.075	1.14	0.562	3.52	43.6
49730		M2	11.08	0.329	4.87	0.255	0.527	6.57	143.6	0.047	0.925	0.423	3.13	62.9
49731		M2	10.57	0.260	6.06	0.248	0.687	5.96	162.4	0.052	0.927	0.546	2.71	44.8
49754		M3	10.72	0.537	4.18	0.404	8.23	7.31	341.0	0.060	4.55	0.711	2.51	44.0
49755		M3	12.04	0.732	4.99	0.411	1.18	8.75	416.3	0.053	1.31	0.660	3.33	44.1
49773		M3	13.39	0.765	4.17	0.442	1.18	9.62	446.4	0.052	1.32	0.522	3.88	57.1
49756		M4	9.69	0.619	5.31	0.269	0.654	6.97	173.8	0.045	0.965	0.407	3.54	56.9
49757		M4	9.43	0.590	5.47	0.280	0.617	6.47	172.6	0.046	0.925	0.428	3.65	53.1
49728		M5	10.04	0.469	6.33	0.291	1.01	6.93	246.9	0.054	0.901	0.626	3.03	50.1
49729		M5	10.37	0.482	5.42	0.312	0.989	7.11	252.5	0.061	0.959	0.632	3.03	50.3
49738		AMIT	10.61	0.093	4.48	0.238	0.470	6.43	126.7	0.063	0.845	0.477	3.56	61.9
49739		AMIT	9.30	0.077	4.39	0.214	0.504	6.04	118.1	0.047	0.694	0.492	3.20	58.7
Background	*Average*		*11.73*		*5.47*	*0.240*	*0.736*	*7.60*		*0.132*		*1.215*		*88.95*
	SD		*1.85*		*2.01*	*0.040*	*0.356*	*0.83*		*0.029*		*0.424*		*12.95*

ID No	Station	As	Au	Cd	Co	Cr	Cu	Fe	Hg	Ni	Pb	Se	Zn
Brown algae – Fucus vesicolosus (mg/kg)													
Detection limits		*0.024*	*0.001*	*0.006*	*0.004*	*0.034*	*0.296*	*2.72*	*0.015*	*0.059*	*0.018*	*0.104*	*0.130*
49746	M1	61.012	0.129	2.044	0.165	0.086	2.608	22.399	*< dl*	0.629	0.038	*< dl*	8.117
49747	M1	58.814	0.124	2.720	0.383	0.068	2.382	19.186	*< dl*	1.381	0.175	*< dl*	6.884
49726	M2	68.078	0.250	2.638	0.371	0.058	4.214	21.359	*< dl*	1.008	0.031	*< dl*	6.500
49727	M2	70.192	0.318	1.720	0.225	0.064	5.575	26.277	*< dl*	0.489	0.033	*< dl*	7.221
49748	M3	69.083	1.137	1.311	0.497	0.086	10.430	35.046	*< dl*	0.892	0.063	*< dl*	8.103
49749	M3	70.938	1.608	1.181	0.600	0.082	21.205	41.801	*< dl*	0.996	0.115	*< dl*	9.576
49750	M4	49.037	0.441	2.388	0.423	0.079	3.749	32.366	*< dl*	1.353	0.043	*< dl*	8.064
49751	M4	57.287	0.430	2.810	0.487	0.052	3.951	23.978	*< dl*	1.411	0.041	*< dl*	9.021
49724	M5	56.690	0.700	1.197	0.379	0.061	9.921	33.320	*< dl*	0.752	0.039	*< dl*	9.548
49725	M5	69.612	0.647	1.196	0.408	0.100	10.198	45.023	*< dl*	0.839	0.060	*< dl*	10.409
49736	AMIT	58.323	0.045	1.989	0.172	0.188	1.595	36.909	*< dl*	0.847	0.040	*< dl*	6.407
49737	AMIT	54.249	0.050	2.001	0.262	0.159	1.423	28.555	*< dl*	0.891	0.037	*< dl*	5.492
Background	*Average*	*46.248*		*1.763*	*0.211*	*0.069*	*1.001*		*0.009*		*0.107*		*7.001*
	SD	*8.432*		*0.576*	*0.046*	*0.076*	*0.237*		*0.006*		*0.043*		*2.088*

ID No	Station	As	Au	Cd	Co	Cr	Cu	Fe	Hg	Ni	Pb	Se	Zn
Sculpin – mg/kg)		*0.024*	*0.001*	*0.006*	*0.004*	*0.034*	*0.296*	*2.72*	*0.015*	*0.059*	*0.018*	*0.104*	*0.130*
Detection limits													
49765	M1	1.356	0.047	0.638	0.039	*< dl*	1.868	83.772	*< dl*	0.084	*< dl*	0.856	28.287
49766	M1	4.452	0.001	1.089	0.012	*< dl*	1.511	16.372	0.034	*< dl*	*< dl*	0.881	33.810
49767	M1	1.435	0.001	0.413	0.008	*< dl*	1.132	26.984	*< dl*	*< dl*	*< dl*	0.743	26.113
49768	M1	2.347	0.002	1.370	0.015	*< dl*	1.178	36.535	0.015	*< dl*	*< dl*	0.714	26.544
49769	M1	2.756	0.001	0.215	0.012	0.097	0.871	42.103	*< dl*	*< dl*	*< dl*	1.103	25.691
49732	M2	2.703	0.002	0.275	0.026	0.071	1.400	68.961	0.021	*< dl*	*< dl*	0.974	30.838
49733	M2	1.820	0.001	0.301	0.010	*< dl*	0.934	16.999	*< dl*	*< dl*	*< dl*	0.572	23.537
49734	M2	1.902	0.002	0.093	0.011	*< dl*	1.661	46.092	0.019	*< dl*	*< dl*	0.958	24.752
49735	M2	2.138	0.002	0.275	0.017	*< dl*	1.294	69.140	*< dl*	*< dl*	*< dl*	1.058	30.297
49779	M2	2.789	0.003	0.463	0.044	*< dl*	2.381	53.895	0.029	*< dl*	*< dl*	0.865	29.541
49781	M3	2.280	0.003	0.348	0.016	*< dl*	1.211	63.937	*< dl*	*< dl*	*< dl*	0.692	19.919
49770	M3	6.395	0.015	0.440	0.072	*< dl*	3.545	260.711	0.027	*< dl*	*< dl*	1.043	41.581
49771	M3	2.124	0.005	0.454	0.036	0.190	1.440	125.345	0.023	*< dl*	*< dl*	0.576	24.970
49772	M3	7.182	0.019	0.461	0.053	*< dl*	4.948	170.218	0.057	*< dl*	*< dl*	1.108	37.089
49780	M3	3.095	0.004	0.264	0.017	*< dl*	1.480	57.383	*< dl*	*< dl*	*< dl*	0.447	22.886
49778	M3	1.150	0.003	0.278	0.012	0.202	1.545	71.641	0.019	0.121	*< dl*	0.729	31.122
49764	M4	1.215	0.001	0.453	0.011	*< dl*	1.118	25.194	0.018	*< dl*	*< dl*	0.774	30.074
49782	M4	2.671	0.001	0.350	0.014	*< dl*	0.973	21.577	*< dl*	*< dl*	*< dl*	0.923	30.419
49783	M4	4.574	0.004	0.357	0.034	*< dl*	3.922	52.138	0.030	*< dl*	*< dl*	0.661	23.904
49784	M4	5.106	*< dl*	0.255	0.006	*< dl*	0.761	29.137	*< dl*	*< dl*	*< dl*	0.629	22.846
49785	M4	20.153	0.001	0.901	0.021	*< dl*	0.825	31.128	0.074	*< dl*	*< dl*	0.604	49.025
49740	Amit	1.895	0.002	0.469	0.015	*< dl*	1.453	37.155	*< dl*	0.070	*< dl*	0.675	23.155
49741	Amit	1.500	0.002	0.364	0.038	0.082	1.472	89.665	*< dl*	*< dl*	*< dl*	0.798	30.037
49742	Amit	1.974	0.001	0.463	0.015	*< dl*	1.120	20.013	*< dl*	*< dl*	*< dl*	0.698	24.771
49743	Amit	1.593	0.001	0.243	0.005	*< dl*	0.743	14.270	*< dl*	*< dl*	*< dl*	0.668	24.797
49744	Amit	2.620	0.001	0.118	0.022	*< dl*	4.036	24.434	*< dl*	*< dl*	*< dl*	0.695	61.162
Background	*Average*	*2.75*		*1.094*	*0.017*	*0.017*	*1.88*	*< dl*	*0.026*		*0.004*		*31.81*
	SD	*1.90*		*0.427*	*0.014*	*0.020*	*0.70*		*0.013*		*0.003*		*1.58*

ID No	Station	As	Au	Cd	Co	Cr	Cu	Fe	Hg	Ni	Pb	Se	Zn
Sediment (mg/kg)													
Detection limits		*12.50*	*0.110*	*0.010*	*0.50*	*2.00*	*0.8*	*40*	*2.480*	*2.10*	*5.10*	*1.200*	*7.00*
49786	W1 Upstream	113.6	1.520	0.100	20.3	107.0	41.1	42722	< dl	48.9	16.9	1.50	67.6
49788	W2 Out mine	401.6	1.635	0.185	36.4	197.5	108.7	71277	< dl	96.1	3.50	1.40	88.3
49789	W3 In sed-bassin	821.1	1.020	0.230	42.1	215.0	152.3	73248	< dl	107.4	4.80	< dl	92.0
49790	W4 out sed bassin	674.6	0.920	0.210	44.6	204.0	204.8	71840	< dl	106.7	8.20	2.30	99.8
49787	W5 Waterfall	47.1	< dl	0.110	9.60	67.0	41.6	26895	< dl	24.0	15.2	1.70	54.0

ID No	Station	As	Au	Cd	Co	Cr	Cu	Fe	Hg	Ni	Pb	Se	Zn
Water (µg/l)													
Detection limits		*0.067*	*0.002*	*0.012*	*0.004*	*0.007*	*0.100*	*0.214*	*0.011*	*0.035*	*0.013*	*0.193*	*0.066*
49792	W1 Upstream	1.01	0.003	*< dl*	0.025	0.052	0.16	8.28	*< dl*	0.061	*< dl*	*< dl*	0.168
49794	W2 Out mine	127.8	26.77	0.016	50.34	0.070	65.6	169.3	*< dl*	15.181	0.018	0.956	0.926
49795	W3 In sed-bassin	21.09	0.383	*< dl*	7.73	0.057	12.9	20.7	*< dl*	0.928	*< dl*	0.609	0.739
49791	W4 out sed bassin	15.47	0.843	*< dl*	7.05	0.072	14.5	11.7	*< dl*	2.100	0.020	0.497	2.432
49793	W5 Waterfall	2.66	0.013	*< dl*	0.107	0.058	0.83	*< dl*	*< dl*	0.258	*< dl*	*< dl*	0.290
MRA Guidelines for water quality		4		0.1		3	2	300	0.05	5	1		10

ID No	Station	As	Au	Cd	Co	Cr	Cu	Fe	Hg	Ni	Pb	Se	Zn
Lichen – Flavocetraria nivalis (mg/kg)													
Detection limits		*0.024*	*0.001*	*0.006*	*0.004*	*0.034*	*0.296*	*2.72*	*0.015*	*0.059*	*0.018*	*0.104*	*0.130*
49704	3	0.273	0.001	0.045	0.112	0.273	0.462	112.9	0.028	0.259	0.536	*< dl*	12.05
49705	4	0.218	0.001	0.028	0.092	0.183	*< dl*	95.0	0.019	0.238	0.425	*< dl*	10.31
49706	5-t	0.557	*< dl*	0.037	0.225	0.538	0.657	290.9	0.023	0.456	0.633	*< dl*	11.30
49707	6-t	1.024	0.006	0.106	0.441	0.743	1.16	331.2	0.022	0.841	0.597	*< dl*	17.52
49708	7	1.529	0.008	0.051	0.459	1.051	1.00	398.0	0.017	0.951	0.587	0.105	15.05
49709	8	1.903	0.007	0.043	0.684	1.524	1.74	577.7	0.016	1.422	0.766	*< dl*	17.42
49710	9	1.350	0.002	0.051	0.338	0.588	0.678	245.0	0.022	0.618	0.842	*< dl*	10.24
49711	10	1.779	0.008	0.051	0.647	1.409	1.64	512.4	0.028	1.272	0.929	0.154	18.54
49712	11-t	2.431	0.012	0.090	0.728	1.417	2.15	527.5	0.022	1.567	1.000	*< dl*	14.15
49713	12-t	0.822	0.007	0.058	0.231	0.615	1.13	267.2	0.026	0.539	0.650	0.130	15.10
49701	15	0.550	0.002	0.046	0.170	0.409	0.646	176.5	0.033	0.447	0.685	*< dl*	14.08
49703	17	0.350	0.001	0.027	0.098	0.194	*< dl*	93.2	0.020	0.181	0.509	*< dl*	12.27
49702	19	0.233	0.002	0.047	0.091	0.262	0.396	119.0	0.019	0.216	0.728	*< dl*	9.65
49714	20-t	0.629	0.004	0.039	0.140	0.402	0.606	193.2	0.028	0.316	0.668	*< dl*	12.05
49745	21-t	1.441	0.007	0.088	0.360	0.998	1.81	395.9	0.030	0.907	0.947	*< dl*	12.06
49715	22-t	2.824	0.011	0.168	3.220	2.293	12.3	870.7	0.022	4.531	1.372	*< dl*	17.28
49716	23-t	1.819	0.015	0.077	0.420	1.231	2.12	465.4	0.028	1.094	0.792	*< dl*	14.44
49717	24-t	1.202	0.015	0.104	0.572	1.522	2.09	570.3	0.028	1.238	1.123	*< dl*	20.97
49719	M1	0.157	0.001	0.038	0.043	0.099	0.477	48.5	0.028	0.083	0.311	*< dl*	12.36
49718	M2	1.134	0.007	0.051	0.170	0.624	0.785	280.2	0.025	0.423	0.555	*< dl*	10.46
49720	M3	0.170	*< dl*	0.038	0.103	0.243	0.543	121.4	0.020	0.212	0.412	*< dl*	18.12
49721	M4	0.159	*< dl*	0.040	0.079	0.263	0.545	163.0	0.026	0.164	0.867	0.115	7.56
49722	M5	0.446	0.001	0.080	0.109	0.202	0.549	120.7	0.026	0.173	0.474	*< dl*	16.55
49723	AMIT	0.093	0.001	0.099	0.097	0.284	0.787	130.5	0.032	0.228	0.434	*< dl*	30.85
Background	*Average*	*0.238*		*0.082*	*0.151*	*0.557*	*0.953*		*0.034*		*1.068*		*21.56*
	SD	*0.264*		*0.030*	*0.146*	*0.992*	*0.757*		*0.006*		*0.338*		*7.237*

ID No	Station	As	Au	Cd	Co	Cr	Cu	Fe	Hg	Ni	Pb	Se	Zn
Arctic Char – Salvelinus alpinus (mg/kg ww) liver													
Detection limits		*0.024*	*0.001*	*0.006*	*0.004*	*0.034*	*0.296*	*2.72*	*0.015*	*0.059*	*0.018*	*0.104*	*0.130*
49758	Waterfall	0.505	0.030	0.167	0.139	*< dl*	20.2	51.5	*< dl*	*< dl*	*< dl*	1.06	33.3
49759	Waterfall	0.162	0.022	0.150	0.020	*< dl*	4.85	53.7	*< dl*	*< dl*	*< dl*	0.65	29.4
49760	Waterfall	0.175	0.019	0.027	0.028	*< dl*	2.22	49.1	0.020	*< dl*	*< dl*	0.716	25.5
49761	Waterfall	0.259	0.004	0.167	0.032	*< dl*	9.29	124.4	0.046	*< dl*	*< dl*	1.04	29.9
49762	Waterfall	0.250	0.212	0.377	0.055	*< dl*	13.4	95.9	0.020	*< dl*	0.036	1.45	29.1
49763	Waterfall	0.143	0.040	0.069	0.034	*< dl*	6.32	36.1	0.009	*< dl*	*< dl*	0.75	30.3
49774	Ref River	0.979	0.099	0.052	0.034	*< dl*	6.45	194.4	0.021	*< dl*	*< dl*	1.20	26.3
49775	Ref River	1.376	0.139	0.102	0.124	0.036	1.87	285.8	*< dl*	*< dl*	*< dl*	1.16	25.6
49776	Ref River	44.8	0.087	0.059	0.136	*< dl*	4.87	320.7	*< dl*	*< dl*	*< dl*	1.16	33.8
49777	Ref River	0.589	0.104	0.105	0.103	*< dl*	2.34	386.0	0.023	*< dl*	*< dl*	1.85	19.1
Background	*Average*	*0.448*		*0.071*	*0.042*	*0.026*	*9.882*		*0.025*		*0.006*		*34.813*
	SD	*0.148*		*0.024*	*0.014*	*0.025*	*10.977*		*0.010*		*0.003*		*4.444*

ENVIRONMENTAL MONITORING AT THE NALUNAQ GOLD MINE, SOUTH GREENLAND, 2013

This tenth environmental monitoring programme was conducted in the Nalunaq area, about 40 km from Nanortalik, South Greenland, from 27 August to 7 September 2013. The environmental monitoring programme is conducted to discover pollution from the mining industry to the environment. Since the monitoring programme in 2012, the mining company Angel Mining Gold A/S has continued to break ore in the mine. The gold was recovered by the use of chemical extraction (carbon-in-pulp) with the use of cyanide. Due to the use of cyanide to extract gold from the ore, there was strict control with the outflow of cyanide from the mine to the valley.

Also an extensive monitoring programme is conducted to reveal spreading and effects of elements into the Kirkespir Valley and Bay environment. The described impact on the environment of the Kirkespir Valley, both terrestrial, freshwater and marine, is considered to be minor and is generally lower than during the operation in 2004-2009.

By November 2013, the mine closed and a local contractor has taken over the clean-up and restoration of the area, which is expected to be completed summer 2014. Environmental monitoring will continue at least three years after the closure and is currently planned to take place in 2014, 2015 and 2016.

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