

# Environmental industrial Waste Management (EWMA)

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**Project information**

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Scientific leader: Jørgen Berge

Project owner: UiT the Arctic University of Norway

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## Summary

EWMA is a result of a pre-project that looked into the interest for establishing a multidisciplinary knowledge group focusing on industrial waste management in cold environment. Questions from the industry were matched with scientists, and these links were used for an application to the Norwegian Research Council (RCN), the Nord Forsk program and Research Initiative North. RCN, Eni Norge AS and UiT finances the EWMA project with ≈100 mill NOK.

The background for the project was to establish an interdisciplinary competence cluster for industrial waste management in petroleum and mineral industry in cold climate. The goal was to conduct research, education and networking as well as being an attractive partner for business, knowledge institutions and authorities.

EWMA has during its project period strongly contributed to the establishment of two new research groups at UiT, environmental geology at the department for geosciences, and ecotoxicology at the department for Arctic and marine biology. The ecotoxicology group branches to Akvaplan niva and UNIS. There has also been several courses and a multidisciplinary bachelor program. 5 PhD candidates successfully defended their thesis and in all 11 Post.Doc candidates has contributed to the massive EWMA production of knowledge. In January 2018, EWMA has published 82 scientific papers, with 20 more in the pipeline. 52 different talks and poster presentations has been given at various events, 27 appearances in newspapers, radio or other media, one book chapter and three workshops/dialogue/networking meeting has been held, where scientists, industry, governmental and nongovernmental organizations came together to discuss the research status and how to go on.

As a spin off, several other projects grew out of EWMA, such as BARCUT, COOPENOR and POLARISATION, all based upon the cooperation, knowledge and people established through EWMA. Spin off projects has supported EWMA activity, vice versa, and has enforced the scientific work and study opportunities. BARCUT will also continue after EWMA ends.

## Scientific highlights

### Exposure of water-soluble fraction of crude oil on eggs and larvae of a high Arctic key species

Increasing anthropogenic activities in the Arctic represent an enhanced threat for oil pollution in a marine environment that is already at risk from climate warming. In particular, this applies to species with free-living pelagic larvae that aggregate in surface waters and under the sea ice where hydrocarbons are likely to remain for extended periods of time due to low temperatures. Nahrgang et al (2016) exposed the positively buoyant eggs of polar cod (*Boreogadus saida*), an arctic keystone species, to realistic concentrations of a crude oil water-soluble fraction (WSF), mimicking exposure of eggs aggregating under the ice to oil WSF leaking from brine channels following encapsulation in ice. Total hydrocarbon and polycyclic aromatic hydrocarbon levels were in the ng/L range, with most exposure concentrations below the limits of detection throughout the experiment for all treatments. The proportion of viable, free-swimming larvae decreased significantly with dose and showed increases in the incidence and severity of spine curvature, yolk sac alterations and a reduction in spine length. These effects are expected to compromise the motility, feeding capacity, and predator avoidance during critical early life stages for this important species. The results imply that the viability and fitness of polar cod early life stages is significantly reduced when exposed to extremely low and environmentally realistic levels of aqueous hydrocarbons, which may have important implications for arctic food web dynamics and ecosystem functioning.

The work received extensive international and national attention, not least from the oil and gas industry itself. The work also resulted in a follow-up experiment initiated in January 2018, representing the lasting effect of EWMA on the research in Tromsø.

### BARCUT, Barents Sea Drill Cuttings Research Initiative

The BARCUT project (2013 – 2019) aims to identify the long-term environmental impact of drill cuttings released to the Barents Sea and address relevant societal concerns. The project is carried out by Akvaplan-niva, Norut Tromsø and UiT The Arctic University of Norway in Tromsø (UiT). Eni Norway AS, fully finances the program with 36 mill NOK, in addition Troms County financed one three-year post doctor position with 2.88 mill NOK. The project has a multidisciplinary approach combining the fields of geology, ecology, molecular- micro- and macro- biology, oceanography, chemistry and social sciences. Cooperation with the petroleum industry also allowed access to equipment that is normally unavailable to Norwegian researchers. Using heavy work class ROV, BARCUT has collected high quality samples of seafloor sediment along transects from wells drilled between 1987 and 2015. These sediment samples are studied in a multidisciplinary way. Additionally, visual studies are done around the wells to see sea floor impact of drill cuttings.

Results corresponds between the disciplines and show different impact on seafloor sediment and biota, depending on what kind of drill fluid used and amount of discharged drill cuttings. The impact is also restricted to areas close to the wells. The project aim to contribute to knowledge- based decision making on handling of drill cuttings in the Barents Sea, and the findings implies that today's procedures for environmental surveys connected to petroleum drilling sites should be adjusted. The findings has been directly presented to the Norwegian environment agency.

The two examples only represent a small fraction of the research carried out by EWMA. For a full overview, see the reference list below. However, both these examples show the importance of the research carried out, not only for the science itself, but also as a vector for establishing long-term and permanent research groups in Northern Norway and Svalbard.

## Outreach and communication

The project web page <http://site.uit.no/ewma>, has communicated research description and activity, events and news during the project period. In January 2018, the publication list has reached 82 scientific papers published, 20 more manuscripts are in the pipeline and will be published after the project ends. The project participants has also been active presenters in different arenas, communicating through poster, talks and interviews. In all there has been 52 poster presentations and talks, 27 popular science publications (interviews etc.) and three work seminars, where authorities, industry, institute sector, NGO`s and universities has come together to discuss the research status and what to do next. Additionally, project participants has contributed on several publications without direct acknowledgement to EWMA. The project has also communicated results and findings directly to the Norwegian Environment Agency, and hopefully, contributed to more informed decision making connected to the petromaritime and mineral industry in northern regions.

## Project participants

### People employed during the project period

- PhD
  - Hanne Vidgren                      UiT Faculty of engineering science and technology
  - Kristine B. Pedersen              UiT Department for Chemistry
  - Melania Borit                        UiT Norwegian college for fishery science
  - Noortje Dijkstra                    UiT Department of Geosciences
  - Yonas Zewdu Ayele                UiT Department for safety and engineer science
- Postdoc
  - Beata Sternal                        UiT Department of Geosciences
  - Helena Reinardy                    The University centre in Svalbard UNIS
  - Ingeborg G. Hallanger            UiT Department of Arctic and marine biology
  - Juho Junntila                        UiT Department of Geosciences
  - Jasmine Nahrgang UiT            UiT Department of Arctic and marine biology
  - Kari Skirbekk                        UiT Department of Geosciences
  - Kristine B. Pedersen                Akvaplan niva
  - Lisa B. Helgason UiT                UiT Department of Arctic and marine biology
  - Melania Borit UiT                    UiT Norwegian college of fishery science
  - Noortje Dijkstra                    UiT Department of Geosciences
  - Xingqiang Song UiT                UiT Department of Arctic and marine biology

- Researcher/amanuensis
  - Jasmine Nahrgang                      UiT Department of Arctic and marine biology
  - Johan Berg Pettersen                      UiT Department of Arctic and marine biology
  - Sophie Bourgeon                      UiT Department of Arctic and marine biology
- Professor II
  - Jolynn Carroll                      Akvaplan niva
  - Johan Berg Pettersen                      NtNU Norwegian university of science and technology
  - Uday Kumar                      Luleå, University of Technology
- RDA Professor
  - John Eirik Paulsen                      Eni Norge AS
  - Salve Dahle                      Akvaplan niva
- Administration
  - Stian Røberg, Project leader                      UiT
  - Jørgen Berge, Scientific leader                      UiT
  - Morten Brattvoll, Senior adviser                      UiT
  - Stine M. Didriksen adviser                      UiT

## Consortium Partners

- National Partners:
  - UiT the Arctic University of Norway
  - Northern Research Institute AS
  - Akvaplan niva
  - The University Centre in Svalbard UNIS
  - Eni Norge AS
  - Narvik university college (UiT)
  - Rambøll Barents Kirkenes
  - Unilab Analyse
  - Norwegian institute for air research (NILU)
- Foreign partners:
  - Technical University of Denmark DTU
  - Rheinisch-Westfälische Technische Hochschule Aachen RWTH-Aachen

## People involved in the different periods and work packages

|                     |            |   |
|---------------------|------------|---|
| Paul F. Wassmann    | Prof.      | UiT Department of Arctic and marine biology |
| Marianne Frantzen   | Researcher | Akvaplan niva                               |
| Elisabeth Halvorsen | Researcher | UiT Department of Arctic and marine biology |
| Christian W. Riser  | Researcher | UiT Department of Arctic and marine biology |
| Marit Reigstad      | Researcher | UiT Department of Arctic and marine biology |
| Javad Barabady      | Professor  | UiT IIS                                     |
| Juho Junttila       | Researcher | UiT Department of Geosciences               |
| Katrine Husum       | Researcher | UiT Department of Geosciences               |
| Tore Lejon          | Professor  | UiT Department of chemistry                 |

|                    |                  |   |
|--------------------|------------------|---|
| Ingar Wasbotten    | CEO              | Unilab Analyse AS                                 |
| Elisabeth Roman    |                  | UiT Faculty of engineering science and technology |
| Aud Helland        | Researcher       | Rambøll Norge                                     |
| Jolynn Carroll     | Prof.II.         | Akvaplan Niva                                     |
| Petter Holm        | Professor        | UiT Norwegian college of fishery science          |
| Ola Engelsen       | Senior scientist | NILU  |
| Jan Schwarzbauer   |                  | RWTH-Aachen                                       |
| Nadia Al Sandouk   |                  | RWTH-Aachen                                       |
| Roland Kallenborn  |                  | UNIS/NILU   |
| Ross Wakelin       |                  | NORUT Narvik                                      |
| Nga Dang           |                  | NORUT Narvik                                      |
| Christian Petrich  |                  | NORUT Narvik                                      |
| Stig Falk Petersen |                  | Akvaplan niva                                     |

### **EWMA Advisory Board all members 2009-2017**

|                  |                     |  |
|------------------|---------------------|--|
| Morten Hald      | UiT                 | Dean Faculty of science and technology           |
| Terje Aspen      | UiT                 | Director Faculty of biology, fishery and economy |
| Inger Ann Hansen | UiT                 | Subdirector Department for communication         |
| Matthias Forwick | UiT                 | Institute leader Department of Geosciences       |
| Liv Nielsen      | Eni Norge AS        | HSEQ Director                                    |
| John E. Paulsen  | Eni Norge AS        | Environment Lead HSEQ                            |
| Dag Nilsen       | NOFI                | R&D manager                                      |
| Tor Husjord      | Maritimt forum nord | CEO  |
| Salve Dahle      | Akvaplan niva       | Director   |
| No show          | Troms County        |  |



# Scientific activities

## EWMA I 2010-2014

During the first period of EWMA, the scientific work consisted of eight work packages focusing on different research-questions connected to industrial waste in cold environment.

**WP1; Biological effects of petroleum related compounds on sub-Arctic and Arctic marine organisms.** Processes in Arctic petroleum related pollution, long term effects, nutrition transfer effects and accumulation in marine species

The increasing human presence in the Arctic shelf seas, linked to the expansion of oil and gas industries and the opening of new maritime routes, poses a risk of acute and long-term diffuse pollution by petroleum compounds. In addition, persistent organic pollutants continue to pose a threat to Arctic organisms with the synthesis and release of more than 100 000 new compounds of unknown effects but with a potential for long-range transport and bioaccumulation into the Arctic food webs. The ecotoxicology group has the goal of studying the effects of pollutants of concern for Arctic and sub-arctic marine organisms and to educate the next generation of ecotoxicologist in and for the High North. Through several projects and in collaboration with many Norwegian and international Institutions, the ecotoxicology group at the university aims at increasing knowledge of biological effects of pollutants which may have significant consequences for populations and ecosystems as a whole. This implies also a basic understanding of the organism's basic biology and ecology and thus a strong integration of basic Arctic ecology and ecotoxicology. The group has a wide range of interests, from molecular modelling, in vitro, physiological and ecosystem based studies.

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- farmed Arctic fox (*Vulpes lagopus*). *Environmental toxicology and chemistry*. 32. 2013. pp1784-92.
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  10. Hegseth M.N., L. Camus, L.B. Helgason, F. Regoli. Hepatic antioxidant responses related to levels of PCBs and metals in chicks of three Arctic seabird. *Comparative Biochemistry and Physiology*. 2011. 154. Pp.28-35.

**WP2; Deposition of drill cuttings in the Barents Sea.** The main goal was to increase knowledge about how cuttings will spread when deposited on the seabed, and to forecast how the contaminants in sediments could be a future source of pollution.

A baseline characterization of sediment properties and polyaromatic hydrocarbons (PAHs) of the Ingøydjupet trough and Tromsøflaket were studied. This was done in order to investigate the sediment transport and deposition by ocean currents to provide insight into the levels and origins of PAHs in a region with petroleum activities in the SW Barents Sea.

Sedimentation rates decrease with distance offshore. Stronger and more variable bottom currents associated with the Norwegian coastal current operate nearshore based on the down-core distribution of sortable silt (SS) and sediment fractions (clay and silt). The most stable bottom currents are associated with the northern Ingøydjupet trough which is under the influence of the North Atlantic Current.

The PAH concentrations are of background (Level I) to good level (Level II) based on the Water Framework Directive classification. The average values were found to be higher than have been reported in previous studies. PAHs in surface samples are mainly of pyrogenic or mixed pyrogenic and petrogenic origin. The observed changes in PAH contents in surface and subsurface sediments vary in accordance with changes in grain size and total organic carbon content. In turn, these sedimentary parameters are naturally controlled by the inflow of Atlantic Water and the strength of the two predominating current systems in this region: the North Atlantic Current and Norwegian Coastal Current.

These baseline findings are of relevance for the petroleum industry in planning environmental assessment and monitoring programs connected to the future expansion of industry activities in this region.

Benthic foraminifera (micro-organism living on the sea-floor) were studied in the southwestern Barents Sea and Hammerfest harbor. The study focused on the response of the micro-organisms to natural and man made environmental changes. The study shows that the southwestern Barents Sea is relatively clean, and the foraminifera are only impacted by natural changes. Benthic foraminifera reflect the environmental baseline of the area. This can be used as a future reference to monitor the long term impact of pollution, for example drill cutting releases, on the Barents Sea seafloor environment. In the Hammerfest harbor, pollution had severe impact on the organisms. Benthic foraminifera accurately reflected the different pollution sources active in the harbor, including high heavy metal concentrations, organic matter enrichment and physical disturbances by ship propellers. Understanding the response of the foraminifera to different types of environmental changes can be used to develop a bio-monitoring tool. Such a bio-monitoring tool based on foraminifera helps to register environment impact rapidly. Because of the expected increase in industrial activities in the Arctic, and consequently the potential for increased industrial discharges into the marine environment, such a bio-monitoring tool is expected to be important for the region.

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**WP3; Mobile electrochemical remediation.** The main goal was to develop mobile test and remedies devices to be used in areas with difficult access.

The WP involved further development of electrokinetic remediation and adaptation to cold climate. The technology was used to optimise the removal of pollutants from contaminated harbour sediments and soil from Arctic locations in Norway, Greenland and NW Russia. An important aspect of the experimental work and data treatment was planning experiments and analysing the results using multivariate statistical analysis. The use of multivariate statistical analysis was a novel approach for designing and optimising remediation, contributing to the development within the field of remediation. Researchers in Denmark and Portugal have recently begun using multivariate analysis for electrokinetic remediation studies.

#### **Selected references:**

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#### **WP4; Sediment behavior and capping technology**, sedimentation and settling modeling.

Development of improved capping methods of contaminated sediments.

Contaminated marine sediments and the increase in suspended sediment concentrations (SSC) pose ecological and human health risks. This raises the need for cost effective and less invasive approaches for sediment management. The remediation methods most widely in use today are dredging, sediment capping, monitored natural recovery and combinations between these. The studies addressed the technical challenges and adverse effects of cap construction, initial cap efficiency during consolidation of the underlying sediments, dredging induced plumes as model input, and monitoring of the suspended sediment plumes arising from the operations.

The current direction within capping technology is towards a thin cap approach, in which the cap construction phase is critical to effectively obtain the required cap thickness. Paper I describes the cap placement as a case study. A mathematical model provided insight into the behavior of the cap material released from the surface. Combined use and different methods to measure the cap

thickness provided the most comprehensive knowledge about the cap coverage and structure. Paper II concerns the stability of the capped confined disposal facility (CDF) during the consolidation of the underlying polluted sediments. The results provided evidence that consolidation-induced pore water advection was able to transport fine particles (< 63 µm) into the cap layer. The study shows the importance of an appropriate cap layer design to minimize the effects of consolidation-induced advective transport. Mathematical modelling is often used to study the fate of suspended sediment plumes induced by dredging. The modelling of material spread requires accurate input data and Paper III addresses how sediment characteristics may affect the dredge plume source terms. Large variation in sediment texture and rheological properties in the river estuary complicates the model input. One of the concerns of the sediment capping is the potential disturbances of in-place sediments arising from the operations and subsequent contaminant release. In Paper IV acoustic and optical methods were applied to monitor suspended sediment plumes arising from cap construction. Acoustic backscatter data provided a better visualization of the extent and shape of the plume. The results provided evidence that in-place sediments were disturbed by the cap placement.

#### **Selected references:**

1. Vidgren, H., Helland, A., and Lepland, A. 2015. Sand cap placement and cap thickness monitoring: A case study at a confined disposal facility. *Remediation Journal*, 25(3): 69–84.
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3. Vidgren, H., and Helland, A. Dredge plume source terms: A case study on sediment characteristics in the Port of Borg. Submitted to *Marine Pollution Bulletin*.
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**WP5; Methodological guidelines for development of best practices for participatory industrial waste management in Arctic and Sub-Arctic areas**, a Norwegian model. How to transfer risk management/principles from individual industries to a complex systemic level. Tractability and certification as control tool. Importance of communication systems between government, industry and civil society

As a consequence of the controversies around extending petroleum activities in the Lofoten-Vesterålen area and in the Arctic, the trust of the Norwegian public in the petroleum industry is falling down, especially when it comes to trusting the industry's environmental discourse. The present study suggests solutions to overcoming this trust problem. Having complexity science as underlying theory, this research builds up on the ideas that: a) risk communication is more effective if it adapts to the culture of the audience, and b) traceability is a good tool for trust-building. This study advances a new theory about how cognitive trust-building processes (CTBPs) are invoked in humans based on cultural belonging. Using a numerical model of the formalized links between four cultural dimensions and CTBPs, the sequence for invoking CTBPs is calculated. Risk communicators

can use this model as a tool to culturally customize their discourse. Considering petroleum non-hazardous production waste (e.g. drill cuttings) as products, traceability could be implemented in their management system. This study gives an overview of relevant traceability definitions. By combining their best parts, a new possible definition that can potentially be applied to any product is proposed. By analyzing the EU legal framework, this research provides theoretical guidelines for implementation of product traceability in any industrial chain. This research has multidisciplinary application, covering international organizational management, organisational behaviour, social psychology, industrial logistics, and the design of socially believable virtual agents in multiagent systems.

**Selected references:**

1. Melania Borit, Jorge Santos (2015). [Getting traceability right, from fish to advanced biotechnological products: a review of legislation](#). Journal of Cleaner Production (104): 13-22.
2. Petter Olsen, Melania Borit (2013). [How to define traceability](#). Trends in Food Science & Technology 29 (2): 142–150.

**Book chapters:**

1. Melania Borit (2016). *Legal requirements for food traceability in the European Union*. [Advances in Food Traceability Techniques and Technologies](#) (ed. Espiñeira & Santaclara). Woodhead Publishing

**WP6; Weathering rates of pollutants and use of drilling fluids as molecular indicators in the Arctic.**

NILU; Meteorological conditions strongly affect degradation rates of substances. The cold Climate along with low amounts of solar light in the Arctic generally result in far slower degradation rates of waste and pollutants than at lower latitudes. Release and handling regulations developed by environmental authorities at mid latitudes may not apply to Arctic conditions, where a much more restrictive regime may be required. Huge knowledge gaps exist with respect to degradation rates in the Arctic. This WP aims to remedy this for the most relevant substances, and thus facilitate for improved policies under arctic conditions. Waste incineration is an important source of atmospheric mercury. Local arctic sources have a much more serious effect on atmospheric concentrations than long-range transported substances. Atmospheric mercury depletion episodes during spring may cause harmful accumulation in biota. We have therefore included studies of AMDEs in this project. Similar methods for estimation of UV radiation for studying AMDEs can also be used for studying degradation of waste.

RWTH; Chemical characterization of polymers in drilling fluids as molecular indicators for the impact of drilling activities in the arctic environment are in refining process.

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**WP7; Separation and treatment of pollution.** Ballast water, oil spill response, waste treatment and bioremediation. The intention was to take the knowledge developed through the contract research activities at Northern Research Institute Narvik, generalize, and tailor it for use in educational courses, and for generating further research projects. Four main thematic areas were identified, which form the basis for grouping research activities: Ballast water treatment, Oil spill response, Waste treatment, Bioremediation

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**WP8; Framework for risk based analysis to identify suitable alternatives for waste handling and management in the high north.** The aim of this research study was to evaluate, identify, and propose a methodology for drilling waste handling practices by considering the complex and fast-changing nature of the Arctic operational conditions. Moreover, the study seek to foster an integrated interdisciplinary understanding of technical and operational risks associated with drilling wastes and their management by implementing the risk-based analysis. Furthermore, the study focuses on developing the concept of a dynamic model for spare parts transportation in Arctic conditions. The result of the study shows that working in the cold Arctic environments has the potential if not managed properly to cause a significant negative effect on the cost elements and the risk of events. Moreover, the result from the temporal link or dynamic Bayesian network based risk analysis demonstrates that these negative impacts of the peculiar Arctic risk influencing factors on the reliability of the waste handling system and the risk of marine pollutions, is more significant with time. Furthermore, the dynamic model analysis results demonstrate that the operating environment of the Arctic region increases the spare parts transportation time significantly, particularly, during winter season, when transporting the spare parts from the southwestern part of Norway to northern Norway.

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## **EWMA II 2015-2017**

In the second period of EWMA (2014-2017) three work packages conducted the scientific work and educational offer.

### **WP1 Environmental effects of discharges and industrial waste**

The overall objective, based on a life cycle analysis perspective, was to identify and fill knowledge gaps that restrict scientific sound decision making, management and selection of best available techniques (BAT) for industrial operations in the northern Norwegian region. To achieve the objective, focused field and experimental effect studies targeting sentinel species of the relevant ecosystems were conducted. The field studies/experiments were planned in close collaboration with the activities conducted through WP2. Three post doc positions have been allocated to the WP1 activities; one ecotoxicologist, one environmental chemist and one social scientist. The post doc candidates have been working as a team in close collaboration with the two associate professors of WP3, the oil and environment research group at Akvaplan-niva, as well as any other relevant partners of the EWMA consortium.

### **Findings**

Dispersion of historically deposited copper-mine tailings in Repparfjorden was shown to be limited. Despite this, there are strong indications that approx. 2-10 tons of copper has been dispersed from the mine tailing deposit to other parts of the fjord. These indications are based on geochemical analysis of sediment in the deposit as well as in other parts of the fjord, and on difference in how copper is bound to the mine tailing sediments and the natural sediments in the fjord. By applying an electric field to newly processed copper mine tailings from the Nussir/Ulveryggen ores, thereby extracting and separating metals and mine tailings, it was shown that up to 70% of copper in the mine tailings could



be extracted. By using this method, an additional 1000 tons of copper per year could be extracted compared to the existing extraction method to be applied when the mine re-opens.

Assessment of environmental impacts of the submarine iron-mine tailings deposit in Bøkfjorden showed that the concentrations of heavy metals in the mine tailings affected sediments were low and although the concentrations of iron were elevated, it was bound in the stable fractions of the particles.

Lab-scale remediation experiments of selected heavy metal polluted shooting range soils were conducted and it was shown that up to 95% of the original content of heavy metals (copper, lead and zinc) could be removed from the three types of soil.

Experimental exposure studies on early life stages of cod to suspended copper-mine tailings particles from Nussir ASA have involved exposure of early life stages of cod embryos, early hatched larvae, and post first feeding larvae to suspended mine tailings particles with and without addition of the chemical flocculent, Magnafloc10. The exposure experiments cover sub lethal molecular effects including genetic and epigenetic changes, stress response gene markers, embryology and developmental abnormalities, cardiac development, growth, hatching, yolk development, mortality, histopathology, and egg buoyancy changes. No negative effects were revealed on cod embryos, although egg buoyancy seems to be altered due to increased number of particles attached to the chorion surface. Epigenetic gene markers and the mortality rate of hatched larvae was significantly affected by dispersed mine tailings.

Molecular mechanisms of sexual development dysfunction in polar cod after long-term recovery from acute exposure to different oil treatments were investigated. This project involved novel development of primers for gene expression on polar cod tissues (brain, gonad, and liver) to cover the hypothalamic-pituitary-gonad axis involved in sex hormone signaling in addition to other markers of PAH toxicity. In total, 17 genes of interest and five control genes were analyzed across the three tissues, providing a large dataset on endocrine disruption in polar cod.

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## **WP2 Deposition of drill cuttings and mine tailings**

The overall objective is to advance the knowledge of spreading of drill cuttings/mine tailing related contaminants after their discharge to the marine environment. This shall be achieved through:

- filling of major gaps in the knowledge of the present sea-bottom contamination
- investigation of the influence of drill cuttings/mine tailing in the past
- improved predictions of future environmental consequences related to pollutant loadings

To answer these questions an integrated, multidisciplinary study will be performed on a selection of sediment surface and core samples. This study will include two research scientists and two post.doc

positions focusing on deposition of drill cuttings and mine tailings. One assistant professor and one post.doc position will connect WP2 with WP1 on Life-Cycle Analysis (LCA) and modelling connected to mine tailings/oil industry related drill cuttings.

### **Findings**

The state of sedimentological environment and contaminant status of Repparfjorden (N Norway) affected by submarine disposal of copper mine tailings during the 1970s were investigated. The overall focus was to track the lateral and vertical extent of the tailings disposed in the inner fjord, based on the analyses of seventeen short sediment cores, retrieved from the entire fjord.

Detailed inspection of the sedimentological (grain size) and geochemical (heavy metal and total organic carbon concentrations) characteristics of the analysed sediment cores allowed to distinguish and track both the distribution of the tailing particles, and the tailing-related contaminants. Whereas the applied geochronological methods ( $^{210}\text{Pb}$  and  $^{137}\text{Cs}$  radioisotopes activity) provided a time frame for this record.

The mine-tailing sediments, those simultaneously deposited with mine tailings and affected the most by the disposal, were found only in cores of the inner fjord along a ~1.5 km long transect. They constitute an up to 9-cm thick layer, 3-9 cm below the core tops, deposited during the 1970s. The strongest influence of the mine tailings occurred in the central part of the inner fjord, close to the location of the probable tailing outlet. Hence, the inner fjord confined by a sill was a major depository for contaminated mine tailings.

Spreading of the tailing-related metal Cu and particles is limited to a relatively small area of the inner fjord to the immediate surrounding sediments and to a discrete layer in one core from the outer fjord most proximal to the sill. Cu concentrations in sediment cores from the inner fjord gradually decrease towards the top core sections, implying physical and/or biological reworking of the sediments after and/or during deposition. Moreover, the lack of a clear tailings signal in the sedimentological record indicates that dispersion of Cu in the water phase is likely. The presence of tailing-affected sediments in layers up to the sediment-water interface indicate that the ecological communities of the inner fjord have been exposed to elevated concentrations of Cu for nearly 40 years.

According to the main research results, two factors mainly control the dispersal of tailings: fjord morphology and sedimentation rate. Although, the strength of the bottom currents in the outer fjord seems to be relatively high, potentially facilitating the spreading of the tailings, the sill is acting as an effective natural barrier for the discharged tailings. The relatively high post-disposal sediment accumulation rate in the inner fjord downgraded the potential impact of the tailings disposal by diluting the tailing-related pollutants in the natural sediments. From the perspective of prospective tailings disposal in Repparfjorden from the reopening Cu mine in Kvalsund municipality it seems crucial to take into account those two aforementioned factors while planning the exact disposal site.

We studied living fauna of benthic foraminifera from Repparfjorden sediment cores, and observed distinct difference in faunal composition between the inner and outer Repparfjord (Finnmark), regardless of contamination. This demonstrates the complexity of benthic foraminiferal distribution in high latitude coastal areas. Within the contaminated inner fjord, distinct variation in faunal

composition occurred at three different levels of copper contamination; one in un-contaminated samples; one when copper contents in the sediments exceeded  $\sim 350 \text{ mg kg}^{-1}$  and one when copper contents exceeded  $\sim 800 \text{ mg kg}^{-1}$ . In the latter category the faunal composition were dominated by epifaunal species; species that live on the sediment surface. Possibly, the copper content reached a level where it was difficult for the infaunal species to succeed. These results indicate that benthic foraminifera appear to be suitable for biomonitoring industrial contamination in high latitude coastal areas.

Results of a comparative LCA study show a trade-off between the benefits of electrolytic tailings remediation (extracting more copper) and the potential impacts of deposited tailings after electrolysis (changes of metal mobility of tailings), indicating the necessity of incorporating different perspective to support the development of more proactive tailings management strategies.

With regard to the research on life cycle impact assessment (LCIA) in the Arctic, our study shows that significant research gaps remain in Arctic-dependent LCIA. In particular, the following two aspects need further attention: (1) the possible influences of the Arctic specific features (e.g. seasonality, cold climate, and marine dependency) on characterization factors for impact assessment in LCA, and (2) the coverage of impact pathways, especially on the under-addressed marine environment and near-shore processes. This study calls for further development of site dependent Arctic LCA, which could increase the credibility of LCA as an environmental decision-support tool for Arctic industrial activities, facilitate better communication among stakeholders, and support sustainable Arctic development.

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### **WP3 Education**

The objective of this work package was to develop study programmes and courses at Bachelor, Master and PhD levels at UiT and in collaboration with EWMA partners within the field of environmental management and ecotoxicology. For this, EWMA II contributed to two permanent associate professor positions to ensure the development of these study programmes, courses and their long-term implementation, even after the end of the EWMA project.

### **Results**

In 2014, EWMA established a new bachelor programme in environmental management and pollution biology at the Faculty of Biosciences, Fisheries and Economics. The programme is offering courses designed to provide a broad biology knowledge base in the first two years of study, and research-based education, specialized in EWMA relevant topics in the final year. Therefore, EWMA designed three custom tailored courses. BIO-2012 and BIO-2013 “Fundamentals in Ecotoxicology” (10ECTS) part I and II respectively are taught by EWMA researchers and post-docs. The courses provide both theoretical and practical knowledge in ecotoxicology and among others petroleum related pollution and mineral waste. The course BIO-2014 “Utplassering i næringslivet” (10ECTS) provides students with an internship in organizations outside academia and provides them therefore with a first professional experience and the possibility to apply their theoretical knowledge in real life situations.

At the Master and PhD levels, the course BIO-3009 Arctic Marine Pollution, has provided a wide range of lectures and seminars relevant to EWMA and taught by EWMA researchers and post-docs. The course is a great success with classes of about 20 students each year.

In collaboration with ARCEX (<http://www.arcex.no>) and UNIS, a new multidisciplinary course at the MSc and PhD level and called “AT333/833 Arctic Petroleum: Challenges for Society, Technology, and Environment (10 ECTS)” has been developed and has been running at UNIS successfully in 2015 and 2017. The course matches the target goal of *EWMAII* of creating synergies between existing projects and Centres through education. This multidisciplinary course incorporates lectures and fieldwork within geology, technology, ecotoxicology and chemistry. More information at <https://www.unis.no/course/at-333-arctic-petroleum-challenges-for-society-technology-and-environment/>.

EWMA II WP3 has created:

- a study Programme at Bachelor level
- custom tailored courses for an research based education in Pollution biology for and in the High North
- a multidisciplinary courses that Integrates competence and people within geology, biology and technology
- Synergies between relevant programmes such as ArCEX

# Project economy

Table I

|                     | 2009 | 2010 | 2011  | 2012  | 2013  | 2014  | 2015  | 2016  | 2017 | Total |
|---------------------|------|------|-------|-------|-------|-------|-------|-------|------|-------|
| <b>Personell</b>    | 263  | 4239 | 6339  | 8960  | 11102 | 10102 | 9868  | 11346 | 6098 | 68316 |
| <b>Bought FoU</b>   |      | 1328 | 2826  | 3232  | 1559  | 1905  | 3335  | 4257  | 2140 | 20582 |
| <b>Running</b>      |      |      | 1713  | 1506  | 1613  | 1737  | 1510  | 1397  | 1360 | 10838 |
|                     |      |      |       |       |       |       |       |       |      |       |
| <b>Total</b>        | 263  | 5567 | 10879 | 13698 | 14274 | 13744 | 14713 | 17001 | 9598 | 99736 |
|                     |      |      |       |       |       |       |       |       |      |       |
| <b>Funding</b>      |      |      |       |       |       |       |       |       |      |       |
| <b>Own</b>          | 8    | 179  | 326   | 411   | 428   | 423   | 1398  | 1411  | 1836 | 6421  |
| <b>Eni Norge AS</b> | 76   | 1614 | 3155  | 3972  | 4140  | 5355  | 6944  | 8126  | 4217 | 37600 |
| <b>RCN</b>          | 178  | 3773 | 7397  | 9315  | 9706  | 7967  | 6371  | 7463  | 3545 | 55715 |
|                     |      |      |       |       |       |       |       |       |      |       |
| <b>Total</b>        | 263  | 5567 | 10879 | 13698 | 14274 | 13744 | 14713 | 17001 | 9598 | 99736 |

Table I: Total spending during project period 2009-2017, numbers \*1000

The total spending on the project period was ≈100 mill NOK. Where the Research council of Norway contributed with 55.7 mill NOK, Eni Norway with 37.6 mill NOK and UiT with 6.4 mill NOK.

## List of publications, outreach and presentations

### Peer-reviewed publications by January 2018

#### 2018

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## Posters and talks

### 2018

1. Song, X., Pettersen, J.B. 2018. Life cycle assessment of subsea copper tailings disposal. Presentation at Arctic Frontiers 2018, 21-26 January 2018, Tromsø.
2. Salve Dahle. Before, during and after EWMA. Arctic Frontiers 2018, 21-26 January 2018, Tromsø.
3. Kristine B. Pedersen. Tailings chemistry. Arctic Frontiers 2018, 21-26 January 2018, Tromsø.
4. Helena Reinardy. Effects of mine tailings exposure on early life stages of cod. Arctic Frontiers 2018, 21-26 January 2018, Tromsø.
5. Melania Borit. The “how” and “why” of using product traceability of documentation of environmental sustainability. Arctic Frontiers 2018, 21-26 January 2018, Tromsø.
6. Juho Junttila. Drill cuttings and mine tailings deposition. Arctic Frontiers 2018, 21-26 January 2018, Tromsø.
7. John Eirik Paulsen. Lessons learned. Arctic Frontiers 2018, 21-26 January 2018, Tromsø.

### 2017

8. Pettersen, J.B., Song, X., 2017. Arctic life cycle impact assessment – gaps in high-north LCA. Poster presentation at the 8th International Conference on Life Cycle Management, 3-6 September 2017, Luxembourg.

### 2016

9. Junttila J, Skirbekk K, Sternal B, Forwick M, Carroll J. Environmental impact of mine tailings deposited in Repparfjorden, Finnmark – Preliminary results. Arctic Frontiers 24-29.01.2016, Tromsø, Norway.
10. Pettersen, J.B., Song, X., 2016. Life Cycle Assessment and Governance: The Case of the High North. Presentation at the SMART Conference “Life-cycle based management and reporting for sustainable businesses”, 29-30 November 2016, Oslo.
11. Melania Borit, Petter Olsen, Jorge Santos (2016) [How to use product traceability for documentation of environmental sustainability in mineral production](#), Northern Regions Geological Resources Conference (GeoNor), Mo i Rana, Norway.
12. Pedersen, K.B. Electrolytic remediation of harbour sediments. Oral presentation. MSSCE 2016, Lyngby, Denmark
13. Pedersen, K.B.; Jensen, P.E.; Ottosen, L.M., Evenset, A.; Christensen, G.N.; Frantzen, M. Metal speciation of historic and new copper mine tailings from Repparfjorden, Northern Norway, before and after acid, base and electrolytic extraction. Oral presentation Sustainable Minerals '16, Falmouth, England
14. Pedersen, K.B. Chemometric analysis for pollution source assessment of harbor sediments in Arctic locations. Oral presentation ARTEK event 2016, Sisimiut, Greenland
15. Pedersen, K.B.; Jensen, P.E.; Sternal, B.; Ottosen, L.M.; Henning M.V.; Kudahl, M.M.; Junttila, J.; Skirbekk, K.; Frantzen, M. Submarine mine tailings disposal in Repparfjorden, northern Norway – long-term dispersion and availability of Cu. Oral presentation ARTEK event 2016, Sisimiut, Greenland
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18. Skirbekk K, Sternal B, Junttila J, Forwick M. Waste management of mine tailings in a vulnerable Arctic environment. Japan Norway Arctic Science and Innovation Week 02-03.06.2016. Tokyo 2016
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23. Sternal B, Junttila J, Pedersen KB, Skirbekk K, Forwick M, Carroll J. 2016. Sedimentological and geochemical record of submarine mine tailing footprint in Repparfjorden (Northern Norway). Geophysical Research Abstracts, Vol. 18, EGU2016-11834, EGU General Assembly 2016.
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32. Junttila J, Skirbekk K, Sternal B, Forwick M, Carroll J. Deponering av gruve avgang. Foredrag. EWMA Dialogues Kirkenes, 10-12 November 2015.
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39. Melania Borit, Loïs Vanhée, Petter Olsen (2014). *Towards enhancing trustworthiness of socially interactive and culture aware robots*. Culture Aware Robotics Workshop (CARs), the 13th International Conference on Autonomous Agents and Multiagent Systems (AAMAS), Paris, France.
40. Pedersen, K.B.; Lejon, T.; Ottosen, L.M.; Jensen, P.E.: Multivariate Analysis of Variable Importance in the Scaling Up of Electrodialytic Removal of Heavy Metals from Harbour Sediments, oral presentation 09.09.14. Symposia on Electrokinetic Remediation (EREM) 2014
41. Pedersen, K.B.; Lejon, T.; Ottosen, L.M.; Jensen, P.E.: Electrodialytic removal of heavy metals from harbour sediments Comparative importance of variables in a 2-compartment cell set-up, poster. Symposia on Electrokinetic Remediation (EREM) 2014

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## 2013

43. Ayele, Y. Z., Barabadi, A., Barabady, J. *Drilling waste handling and management in the High North*. In Proceeding of the IEEE International Conference on Industrial Engineering and Engineering Management (IEEM 2013), Bangkok, Thailand, 10 – 13 December 2013. pp. 673 – 678. DOI: [10.1109/IEEM.2013.6962496](https://doi.org/10.1109/IEEM.2013.6962496)
44. Junttila, J., Carroll, J., Husum, K., Dijkstra, N., 2013. Sediment accumulation areas and sediment transportation in Ingøydjupet, SW Barents Sea. AMGG 2013
45. Melania Borit, Lois Vanhée, Petter Olsen (2013). *Theoretical Considerations for Enhancing Social Believability through Integrating Culturally Specific Trust-Building Cognitive Features in Non-Playing Characters*. Social Believability in Games Workshop (SBGW), the 10th Conference for Advances in Computer Entertainment (ACE), Twente, The Netherlands.
46. Pedersen, K.B.; Kirkelund, G.M.; Ottosen, L.M. ; Jensen, P.E.; Lejon, T. Multivariate Analysis of Electrodialytic Remediation of Polluted Harbour Sediments, oral presentation 25.06.2013. Symposia on Electrokinetic Remediation (EREM) 2013
47. Pedersen, K.B. Waste management, presented 19.09.2013. Invited speaker for internal DNV/Statoil seminar 'Arctic Competence Escalator, workshop 2.1' 2013

## 2012

48. Dijkstra, N., Junttila, J., Husum, K., Carroll, J., Klitgaard-Kristensen, D. and Hald, M., 2012. Benthic foraminifera as indicators of pollution in high latitude marine environments. European Geoscience Union General Assembly, Vienna, Austria, Geophysical Research Abstracts Vol. 14, EGU 2012-4722, 2012.
49. Dijkstra, N., Junttila, J., Carroll, J., Husum, K., Hald, M., 2012. Using benthic foraminifera as bioindicators of pollution in the SW Barents Sea. 30th Nordic Geological Winter Meeting, 9-12.1.2012, Reykjavik, Iceland. Abstract pp. 99.
50. Junttila, J., Dijkstra, N., Carroll, J., Hald, M., 2012. Anthropogenic pollutants in surface sediments of SW Barents Sea. 30<sup>th</sup> Nordic Geological Winter Meeting, 9-12.1.2012, Reykjavik, Iceland. Abstract pp. 99.
51. Pedersen, K.B. Environmental Management of Industrial Waste in the High North: Electrochemical Remediation of Polluted Sediments in the Arctic, presented 10.02.2012. Invited speaker to Barents Spektakel 2012.

## 2011

52. Pedersen, K.B. Mobile remediation of remediated sediments – developing an industrial research project (in Norwegian) Presented 14.11.2011. Invited speaker to The Norwegian Research Council Northern Areas Conference 2011.



## Outreach: Popular science articles, news stories, talks and blogs

The project website <https://site.uit.no/ewma/> has been the forum for news and information about EWMA activity. Listed below is interviews and articles published in other media.

### 2016

1. Christiansen, Atle; Røberg, Stian. Forskere gikk til bunns i Barentshavet. <https://www.forskningsradet.no/prognett-nordsatsing/Nyheter> [Internett] 2016-02-19 UiT
2. Christiansen, Atle; Røberg, Stian. Kampen om Repparfjorden. <https://www.forskningsradet.no/prognett-nordsatsing/Nyheter/> [Internett] 2016-02-02 UiT
3. Røberg, Stian. Environmental waste management 2010-2017. Forskningsløft i nord, Forskningsrådet 15.01.2016
4. Skirbekk, K. Intervju på forskningsraadet.no "Kampen om Repparfjorden" (02.02.2016) [https://www.forskningsradet.no/prognett-nordsatsing/Nyheter/Kampen\\_om\\_Repparfjorden/1254015840545/p1228296261516](https://www.forskningsradet.no/prognett-nordsatsing/Nyheter/Kampen_om_Repparfjorden/1254015840545/p1228296261516)
5. Skirbekk, K. Intervju i High North News "Vil tette kunnskapshull om sjødeponi" (24.04.2016) <http://www.highnorthnews.com/vil-tette-kunnskapshull-om-sjodeponi/>
6. Skirbekk, K. Intervju i Fiskeribladet Fiskaren "Forsker på konsekvenser om sjødeponi" (01.05.2016) <https://fiskeribladet.no/nyheter/?artikkel=46724>
7. Tomassen, Jan Harald; Røberg, Stian. Oljemillioner gir unik kunnskap om havbunnen. <https://www.nrk.no/finnmark/oljemillioner-til-unik-havbunnsf> [Internett] 2016-03-04 UiT

### 2015

8. Nahrgang, J., Røberg, S., Arctic challenges: climate and petroleum resources. Global Scientia Issue 4 2015
9. Røberg, Stian. Environmental Waste Management EWMA. A multidisciplinary competence cluster within industrial waste management in cold environments. Arctic Frontiers; 2015-01-18 - 2015-01-23 UiT
10. Røberg, Stian. Environmental Waste Management Centre. Oljeindustriens miljø og teknologikonferanse 2015; 2015-03-10 - 2015-03-11 UiT
11. Røberg, Stian. Environmental Waste Management EWMA. A multidisciplinary competence cluster within industrial waste management i cold environments. GeoNor-Konferansen 2015. Industriell verdiskapning basert på geologiske ressurser i Nordområdene; 2015-03-25 - 2015-03-26 UiT

### 2014

12. Christiansen, Atle; Røberg, Stian. Næringslivsløft i nord. <https://www.forskningsradet.no/prognett-nordsatsing/Nyheter/> [Internett] 2014-01-23 UiT
13. Nahrgang, J., Korshunova, E., Miljøovervåkning i, av og for nordområdene: Har vi lokal kompetanse for å utvikle overvåkningsprogrammer som sikrer at miljøet ikke er den tapende part? Nordlys 11.03.2014
14. Røberg, Stian; Berge, Jørgen. Næringsliv og forskning. Barentshavskonferansen; 2014-03-31 - 2014-04-02 UiT

## 2013

15. Christiansen, Atle; Røberg, Stian. Nord-Norge lykkes med kompetanseutvikling. Nord-Norge lykkes med kompetanseutvikling [Internett] 2013-07-02 UiT
16. Hald, Morten; Røberg, Stian. Blått hav hvite strender. Nordområdekonferansen; 2013-11-20 - 2013-11-21 UiT
17. Os, Vibeke; Dijkstra N. Forurensning av Barentshavet overvåkes med mikroorganismer. Press release by UiT regarding PhD dissertation, [https://uit.no/nyheter/artikkel?p\\_document\\_id=358280](https://uit.no/nyheter/artikkel?p_document_id=358280)

## 2012

18. Røberg, Stian. Hvordan realisere kravet om nullutslipp i polare strøk? Kystens energi; 2012-02-08 - 2012-02-09 UiT

## 2011

19. Liv Nielsen. EWMA. Årets forskningsløft- Narvik 3-4 mai 2012.
20. Røberg, Stian. Farlig avfall fra arktisk oljeindustri og skipsfart. NORSAS Konferanse for Farlig avfall 2011; 2011-09-20 - 2011-09-21 UiT
21. Røberg, Stian. Forskningsutfordringer for operasjoner i nordområdene: Avfallshåndtering i arktisk miljø. Nordområdekonferansen; 2011-11-14 - 2011-11-15 UiT
22. Røberg, Stian; Brattvoll, Morten. Environmental Waste Management. CSIS seminar, Tromsø Forum on Atlantic media and the environment (FAME-V); 2011-06-07 - 2011-06-07 UiT
23. Torsvik, Nils. 70 millioner til forskning på nullutslipp. Fiskeribladet Fiskaren 28.09.2011

## 2010

24. Røberg, Stian. Environmental Industrial Waste Management (EWMA). Oil and Gas Development in the High North; Norwegian energy partners - INTZOK 2010-01-26 - 2010-01-29 UiT
25. Fredriksen, S.S. Forsker på miljøforsvarlig håndtering av avfall i Arktis. Nordlys 10.07.2010

## 2009

26. Røberg, stian; Barlindhaug, John; Brattvoll, Morten. Environmental Waste Management -En kompetanseklunge for industriell avfallshåndtering i kaldt klima-. Tromsø: Universitetet i Tromsø, U-VETT 2009 31 s. UiT
27. Røberg, Stian; Brattvoll, Morten. Northern environmental waste management. Forskningsrådets Nordområdekonferanse; 2009-11-25 - 2009-11-26 UiT

## Book Chapters

2016

1. Melania Borit (2016). *Legal requirements for food traceability in the European Union*. [Advances in Food Traceability Techniques and Technologies](#) (ed. Espiñeira & Santaclara). Woodhead Publishing

## Workshops/Conferences

2018

1. Arctic Frontiers PhD workshop, Young scientist forum (YSF) 21-31 January 2018.
2. Industrial Waste management in Arctic waters - closing session for the EWMA programme Arctic Frontiers 25 January 2018 Tromsø

2015

3. Environmental Industrial Waste Management (EWMA) Multidisciplinary industrial waste management in cold environment. EWMA Dialogues Kirkenes 10-12 November 2015. Mineral extraction and sea deposition of tailings. What is the environmental impact, and how do we achieve adequate sustainability oriented decision making?

2009

4. Workshop about establishing a competence centre for industrial waste management, business, industry and R&D. 08.05.2009 UiT

# Appendix: PhD and Post.Doc presentation

**Full name:** Beata Sternal  
**Employment category:** Postdoc  
**Employment period:** 04.05.2015 – 03.05.2017  
**Employer:** Department of Geosciences, UiT The Arctic University of Norway in Tromsø  
**EWMA WP:** 2. Deposition of drill cuttings and mine tailing  
**WP-leader:** Juho Junttila



## Reviewed research papers:

1. Sternal B, Junttila J, Skirbekk K, Forwick M, Carroll J, Pedersen KB. The impact of submarine copper mine tailing disposal from the 1970s on Repparfjorden, northern Norway. *Marine Pollution Bulletin* 2017, Volume 120 (1-2):136-153.  
<https://doi.org/10.1016/j.marpolbul.2017.04.054>
2. Pedersen, Kristine Bondo; Jensen, Pernille E.; Sternal, Beata; Ottosen, Lisbeth M.; Henning, Mie Vesterskov; Kudahl, Manja Marie; Junttila, Juho; Skirbekk, Kari; Frantzen, Marianne. Long-term dispersion and availability of metals from submarine mine tailing disposal in a fjord in Arctic Norway. *Environmental Science and Pollution Research* 2017.  
<https://doi.org/10.1007/s11356-017-9276-y>

## Conferences, meetings:

1. Sternal B, Junttila J, Pedersen KB, Skirbekk K, Forwick M, Carroll J. Sedymentologiczny i geochemiczny zapis oddziaływania odpadów po flotacji rud miedzi w osadach fiordu Repparfjord (północna Norwegia). Scientific meeting at the Institute of Geology, Adam Mickiewicz University in Poznań, 27.09.2016, Poland [invited talk].
2. Skirbekk K, Sternal B, Junttila J, Forwick M. Waste management of mine tailings in a vulnerable Arctic environment. Japan Norway Arctic Science and Innovation Week 02-03.06.2016.
3. Sternal B, Junttila J, Pedersen KB, Skirbekk K, Forwick M, Carroll J. 2016. Sedimentological and geochemical record of submarine mine tailing footprint in Repparfjorden (Northern Norway). *Geophysical Research Abstracts*, Vol. 18, EGU2016-11834, EGU General Assembly 2016.

4. Skirbekk K, Dijkstra N, Junttila J, Sternal B, Pedersen KB, Forwick M, Carroll J. Biomonitoring polluted sediments in Arctic regions - possibilities and challenges using benthic foraminifera. Case studies from northern Norway. Geophysical Research Abstracts Vol. 18, EGU2016-7362, EGU General Assembly 2016
5. Skirbekk K, Sternal B, Junttila J, Pedersen KB, Forwick M. Sub-marine mine tailings in Repparfjorden. Geonor 15-17.03.2016.
6. Skirbekk K, Sternal B, Junttila J, Forwick M. Sub-marine waste deposits in Repparfjorden. Past and Future. Arctic Frontiers 24-29.01.2016, Tromsø, Norway.
7. Junttila J, Skirbekk K, Sternal B, Forwick M, Carroll J. Environmental impact of mine tailings deposited in Repparfjorden, Finnmark – Preliminary results. Arctic Frontiers 24-29.01.2016, Tromsø, Norway.
8. Junttila J, Skirbekk K, Sternal B, Forwick M, Carroll J. Deponering av gruve avgang. Foredrag. EWMA Dialogues Kirkenes, 10-12 november 2015.
9. Skirbekk K, Sternal B, Junttila J, Forwick M, Carroll J. Environmental impact of submarine mine tailings deposited between 1972-1978 in Repparfjorden, northern Norway – preliminary results. Arctic Workshop 10-13.05.2015.

#### **Summary of the scientific research findings:**

During the course of scientific research within the WP2 of EWMA project the state of sedimentological environment and contaminant status of Repparfjorden (N Norway) impacted by submarine disposal of copper mine tailings during the 1970s were investigated. The overall focus was to track the lateral and vertical extent of the tailings disposed in the inner fjord, based on the analyses of seventeen short sediment cores, retrieved from the entire fjord.

Detailed inspection of the sedimentological (grain size) and geochemical (heavy metal and total organic carbon concentrations) characteristics of the analysed sediment cores allowed to distinguish and track both the distribution of the tailing particles, and the tailing-related contaminants. Whereas the applied geochronological methods ( $^{210}\text{Pb}$  and  $^{137}\text{Cs}$  radioisotopes activity) provided a time frame for this record.

The mine-tailing sediments, those simultaneously deposited with mine tailings and affected the most by the disposal, were found only in cores of the inner fjord along a ~1.5 km long transect. They constitute an up to 9-cm thick layer, 3-9 cm below the core tops, deposited during the 1970s. The strongest influence of the mine tailings occurred in the central part of the inner fjord, close to the location of the probable tailing outlet. Hence, the inner fjord confined by a sill was a major depository for contaminated mine tailings.

Spreading of the tailing-related metal Cu and particles is limited to a relatively small area of the inner fjord to the immediate surrounding sediments and to a discrete layer in one core from the outer fjord most proximal to the sill. Cu concentrations in sediment cores from the inner fjord gradually decrease towards the top core sections, implying physical and/or biological reworking of the sediments after and/or during deposition. Moreover, the lack of a clear tailings signal in the sedimentological record indicates that dispersion of Cu in the water phase is likely. The presence of tailing-affected sediments in layers up to the sediment-water interface indicate that the ecological communities of the inner fjord have been exposed to elevated concentrations of Cu for nearly 40 years.

According to the main research results the dispersal of tailings is mainly controlled by two factors: fjord morphology and sedimentation rate. Although, the strength of the bottom currents in the outer fjord seems to be relatively high, potentially facilitating the spreading of the tailings, the sill is acting as an effective natural barrier for the discharged tailings. The relatively high post-disposal sediment accumulation rate in the inner fjord downgraded the potential impact of the tailings disposal by diluting the tailing-related pollutants in the natural sediments. From the perspective of prospective tailings disposal in Repparfjorden from the reopening Cu mine in Kvalsund municipality it seems crucial to take into account those two aforementioned factors while planning the exact disposal site.

Full name: **Hanne Vidgren**  
Employment category: PhD  
Employment period: from July 2011 to March 2015  
Where: UiT – Narvik campus / Rambøll Norway  
Supervisor: Aud Helland Rambøll Norway, Juho Junttila UiT  
EWMA WP: WP 2: Deposition of drill cuttings and mine tailing  
Title of dissertation: Remediation of contaminated marine sediments - Sediment capping technology and adverse effects of remediation actions

#### **Publications:**

5. Vidgren, H., Helland, A., and Lepland, A. 2015. Sand cap placement and cap thickness monitoring: A case study at a confined disposal facility. *Remediation Journal*, 25(3): 69–84.
6. Vidgren, H., Helland, A., and Lepland, A. Stability of capped dredged sediments in a confined disposal facility at Malmøykalven, Oslofjord, SE-Norway. *Soil and Sediment Contamination: International Journal*, 24(6): 675-693.
7. Vidgren, H., and Helland, A. Dredge plume source terms: A case study on sediment characteristics in the Port of Borg. Submitted to *Marine Pollution Bulletin*.
8. Vidgren, H. Use of combined monitoring system to evaluate the potential for resuspension during sand cap placement. Manuscript.

#### **Scientific description**

Contaminated marine sediments and the increase in suspended sediment concentrations (SSC) pose ecological and human health risks. This raises the need for costeffective and less invasive approaches for sediment management. The remediation methods most widely in use today are dredging, sediment capping, monitored natural recovery and combinations between these. The studies addressed the technical challenges and adverse effects of cap construction, initial cap efficiency during consolidation of the underlying sediments, dredging induced plumes as model input, and monitoring of the suspended sediment plumes arising from the operations.

The current direction within capping technology is towards a thin cap approach, in which the cap construction phase is critical to effectively obtain the required cap thickness. Paper I describes the cap placement as a case study. A mathematical model provided insight into the behaviour of the cap material released from the surface. Combined use of different methods to measure the cap

thickness provided the most comprehensive knowledge about the cap coverage and structure. Paper II concerns the stability of the capped confined disposal facility (CDF) during the consolidation of the underlying polluted sediments. The results provided evidence that consolidation-induced pore water advection was able to transport fine particles ( $< 63 \mu\text{m}$ ) into the cap layer. The study shows the importance of an appropriate cap layer design to minimize the effects of consolidation-induced advective transport. Mathematical modelling is often used to study the fate of suspended sediment plumes induced by dredging. The modelling of material spread requires accurate input data and Paper III addresses how sediment characteristics may affect the dredge plume source terms. Large variation in sediment texture and rheological properties in the river estuary complicates the model input. One of the concerns of the sediment capping is the potential disturbances of in-place sediments arising from the operations and subsequent contaminant release. In Paper IV acoustic and optical methods were applied to monitor suspended sediment plumes arising from cap construction. Acoustic backscatter data provided a better visualization of the extent and shape of the plume. The results provided evidence that in-place sediments were disturbed by the cap placement.

**Full name:** **Helena Reinardy**  
**Employment category:** EWMA post-doctoral scientist  
**Employment period:** September 2015 - November 2017  
**Employer:** The University centre in Svalbard UNIS  
**EWMA WP:** EWMA II WP1 Environmental Effects of operational discharges and industrial waste  
**WP-leader:** Marianne Frantzen Akvaplan niva



### **Scientific activities**

My research has been on investigating a broad range of effects in marine organisms exposed to industrial waste. Based on the case study of the planned future release of mine tailings from the Nussir copper mine into Repparfjorden, I have conducted two large experiments exposing early life stages of Atlantic cod to the mine tailings. The first experiment exposed newly fertilised cod embryos to the fine fraction mine tailings, and measured their development and survival over a month-long exposure. Embryonic development appeared unaffected, but with the loss of the protective chorion with hatching, there was an increase in larval mortality, likely due to direct contact with suspended particles in the water. Extensive analyses included characterisation of metal concentrations in the water, hatched chorions, and larvae, visualisation of particles adhered to the chorion surface,

growth, cardiac activity, and gene expression of a panel of general stress responses in addition to a focus on geno- and epigeno-toxicity genes. Genome methylation is important fundamental life process, and patterns of methylation is determined early in development; key DNA and histone methyltransferases were significantly altered in larvae exposed to mine tailings. This initial experiment showed both acute and chronic effects of suspended mine tailings on sensitive early life stages of cod. The second experiment built on the first and included higher exposure concentrations and an additional treatment factor of the flocculant Magnafloc. Pre-hatch embryos were found to have altered buoyancy, likely linked to more adhered particles on the chorion surface. Larval mortality was shown to be increased again, and larval histology will investigate gross pathological effects in gills and early organogenesis. Larval behaviour was not found to be affected. I am leading a project with Masters student, Ditte Secher Paludan, to investigate endocrine disruption in polar cod exposed to oil residues remaining in the environment after different oil spill remediation (OSR) actions by qRT-PCR analysis brain, gonad, and liver tissue of a wide range of genes controlling production of key hormones and enzymes involved in sexual maturation in females. In UNIS, I have developed gene expression analyses as tools for arctic ecotoxicology in general, with a focus on development of gene markers for epigenetic and genotoxic response mechanisms in cod. I have joined the supervisory team for a PhD student, Tatiana Drotikova, who is analysing production, transport, and fallout of nitro- and oxy-PAHs from coal-fired power stations in Svalbard. I am developing collaborations with national and international researchers for future projects in molecular toxicology, fish toxicology, and arctic molecular biology. I have been promoted to Associate Professor, I am leading two masters-PhD level courses and a Bachelor level course, and I am actively involved in developing the future strategy for environmental sciences in UNIS. I am co-organiser in the annual Norwegian Environmental Toxicology Symposium that I will be hosting in UNIS in spring 2018.

**Publications *In prep:***

*In prep:* Acute and chronic effects of fine fraction mine tailings on early life stages of Atlantic cod.

*In prep:* Implications of mine tailings exposure on Atlantic cod development and survival.

*In prep:* Magnafloc flocculant affects mine tailings particles interaction with early life stages of cod.

*In prep:* Reproductive hormone dysfunction in female polar cod exposed to oil residues.

Emerson *et al.* 2017. *Ocean acidification impacts spine integrity but not regenerative capacity of spines and tube feet in adult sea urchins.* Royal Society Open Science 4:170140.

**Proposals:**

NRC 2017: Effects of mine tailings sea deposition on early life stages of Atlantic cod. Fram Centre

2017: WP Epigeno-toxicological effects of oil exposed on early life stages of polar cod. Fram Centre

2017: Does ocean acidification affect gamete quality in an arctic calanoid copepod? NRC 2017:

Education and training program for children to communicate on nature and environmental issues.

“KULARCTIC”. NRC 2017: 7<sup>th</sup> NETS meeting: Towards a solution for pollution in a warming Arctic



**Full name:** Ingeborg Gammelsæter Hallanger  
**Employment category:** EWMA post-doctoral scientist  
**Employment period:** January 2012 – March 2017  
**Employer:** UiT AMB  
**EWMA WP:** EWMA I WPI Effects of pollutants on sub-arctic and arctic marine organisms  
**WP-leader:** Paul Wassmann

**Scientific activities:**

My research within EWMA has been diverse concerning contaminated organisms and effects studied. The effects of exposure to several compounds found in produced water mixture of selected organic compounds (APW), radium-226 (Ra-226), barium (Ba), and a scale inhibitor on the copepod species *Calanus finmarchicus*. Experiments were performed using exposure concentrations at realistic levels. Significantly lower survival in the APW exposure groups was found. In addition, adult females were exposed to APW, Ra-226, and a mixture of the two. Both individual-level effects (egg production and feeding) and molecular-level effects (gene expression) were assessed. (Jensen L.K., Halvorsen E., Song Y., **Hallanger I.G.**, Hansen E.L., Brooks S., Hansen B.H., Tollefsen K.E., 2016. Individual and molecular level effects of produced water contaminants on nauplii and adult females of *Calanus finmarchicus*. J. Toxicol. Environ. Health, Part A 79:13-15, 585-601)

1. In Kongsfjorden, Svalbard, no seasonal pattern was observed within the benthic community for legacy persistent organic pollutants (POPs). (Evenset A., **Hallanger I.G.**, Tessmann M., Warner N.A., Ruus A., Borgå K., Gabrielsen G.W., Christensen G.N., 2016. Seasonal variation in accumulation of persistent organic pollutants in an Arctic marine benthic food web. Sci.Total Environ. 542, 108-120.)
2. Organophosphorus flame retardants was reported for the first time from Svalbard, Norway, and the levels are relatively high compared to urban and industrialized areas. (**Hallanger I.G.**, Sagerup K., Evenset A., Kovacs K.M., Leonards P., Fuglei E., Routti H., Aars J., Strøm H., Lydersen C., Gabrielsen G.W., 2015. Organophosphorous flame retardants in biota from Svalbard, Norway. Marine Pollution Bull 101:1, 442-447.)
3. Chiral compounds, such as  $\alpha$ -HCH and chlordanes, and their enantiomer fraction can be a useful scientific tool to elucidate climate change driven processes in an ice influenced Arctic food chain. (Carlsson P., Warner N.A., **Hallanger I.G.**, Herzke D., Kallenborn R., 2014. Spatial distribution of chiral pesticides in *Calanus* spp. from three Arctic fjords. Environ Pollution 192, 154-161. )
4. New knowledge regarding life history traits for the polar cod (*Boreogadus saida*) was described. Growth and reproduction is impaired in warmer waters (Atlantic influenced) compared to cold waters (Arctic influenced). (Nahrgang J., Varpe Ø., Korshunova, E., Murzina S., **Hallanger I.G.**, Vieweg I., Brge J., 2014. Gender specific reproductive strategies of an Arctic key species (*Boreogadus saida*) and implications of climate change. PLoS one, 9:5, e98452.)
5. Male juvenile Arctic foxes exposed to a diet of environmental realistic concentrations showed evidence of lower testosterone levels than unexposed juvenile foxes. (**Hallanger, I.G.**, Jørgensen E.H, Fuglei, E., Ahlstrom, O., Muir, D., Jenssen, B.M., 2012. Dietary contaminant exposure affects plasma testosterone, but not thyroid hormones, vitamin A and

vitamin E in male juvenile arctic foxes (*Vulpes lagopus*). J. Toxicol. Environ. Health, Part A 75:21, 1298-1313.)

6. Together with the University of Bergen, NILU, and WHOI I have tried to implement and validate two methods for sampling cod liver to be used in exposure studies of contaminants at UiT. This project resulted in one master student and two publications in preparation. (*In prep*: Cordery K.I., Geraudie P., Helgason L.B., Gerbron M., Eide M., Pickford D., **I. G. Hallanger I.G.**, *Ex vivo* liver culture in Atlantic cod: comparison of precision-cut slices and explants; *In prep*: Aluru N., **Hallanger I.G.**, McMonagle H., Harju H., Transcriptomic changes associated with exposure to organophosphate flame retardants in Atlantic cod liver)

**Proposals:**

2013: "Effects of organophosphorous flame retardants in benthic and pelagic Arctic fish species" (335 000 NOK) financed through Fram Centre Flagship "Hazardous substances".

**Master student:**

Katherine Isabelle Cordery, 2013 «A comparison of two sampling methods for *in vitro* culture of hepatic tissue from Atlantic cod (*Gadus morhua*).

|                             |   |
|-----------------------------|---|
| <b>Full name:</b>           | <b>Jasmine Nahrgang</b>   |
| <b>Employment category:</b> | EWMA post-doctoral scientist  |
| <b>Employment period:</b>   | September 2011 - October 2014   |
| <b>Employer:</b>            | <b>UiT AMB</b>  |
| <b>EWMA WP:</b>             | <b>EWMA I - WP1 Biological effects of petroleum related compounds on sub-Arctic and Arctic marine organisms</b> |
| <b>WP-leader:</b>           | <b>Paul Wassmann</b>  |
| <b>EWMA II:</b>             | <b>Associated professor and WP leader WP3 Education</b>   |

**Scientific activities**

**During EWMA I**, my main research activities dealt with the sensitivity of an Arctic key species to petroleum discharges. Past experience has shown that releases of crude oil can have important long-term ecosystem effects at the regional level, leading to significant economic consequences through the loss of ecosystem services. In ice-covered environments, oil recovery is considered exceptionally challenging because the remoteness of the Arctic renders detection and access to the impacted area difficult, especially during the polar night. Spilled oil can easily become encapsulated into the ice and released in the following melt seasons when it may be widely distributed over larger areas; this will potentially affect ecosystems during periods of high productivity and at biological hotspots. Polar cod (*Boreogadus saida*) is the most abundant pan-Arctic fish species, and it sustains the majority of other species that comprise higher trophic levels. Impacts from anthropogenic pollution, and in particular accidental oil spills, may play a role in the decline of this key species and thereby its central role in the Arctic food web. My studies aimed at providing novel insights into the sensitivity of both adult polar cod and their early life stages to crude oil exposure. With additional funding through the FRIMEDBIO project POLARISATION (NCR#214184), a total of 11 experimental studies were carried out from short (days) exposures of *in vitro* systems to medium (weeks) and long-term (months) *in vivo* exposures of polar cod. These provided new knowledge related to 1) the toxicokinetics of

polycyclic aromatic hydrocarbons (PAHs) in dietary exposed polar cod, 2) some pathways of toxicity and 3) the sensitivity of adults and early life stages to exposure to dietary and waterborne crude oil, respectively. Among all results obtained within the project, the key findings included differential body distribution of different PAH compounds but no significant effects of different temperatures (0 and 6°C) on their toxicokinetics. Also, depending on exposure doses, differential toxicity pathways seemed to be activated in polar cod. At environmentally realistic levels of crude oil dietary exposure, lipid homeostasis seemed to be altered, at least to some degree at the physiological level, although clear effects were not observed at transcription levels. Long-term exposure to low levels of dietary crude oil altered sperm quality in males, but no effects were observed for plasma levels in sex steroid hormones or oocyte maturation. Pelagic embryos and larvae were, on the contrary, highly sensitive to extremely low levels of water-soluble fraction of crude oil, showing significant and dose-dependent malformations and reduced growth. **During EWMA II**, a follow up study consisted in the embryotoxicity of crude oil to first-feeding larvae, including behavioural endpoints. This study is currently under analysis.

My main role in EWMA II was to establish a Bachelor programme “Arctic Pollution Biology and management” at UiT/BFE and associated course. The programme started officially in 2014. Three custom tailored courses were implemented:

- BIO 2012 Fundamentals in Ecotoxicology, part II  
([https://en.uit.no/education/courses/course?p\\_document\\_id=508103&ar=2017&semester=H](https://en.uit.no/education/courses/course?p_document_id=508103&ar=2017&semester=H))
- BIO 2013 Fundamentals in Ecotoxicology, part II  
([https://en.uit.no/education/courses/course?p\\_document\\_id=508172&ar=2017&semester=H](https://en.uit.no/education/courses/course?p_document_id=508172&ar=2017&semester=H))
- BIO 2014 Utplassering i næringslivet og Forvaltning  
(<https://uit.no/utdanning/emner/emne/490394/bio-2014?ar=2017&semester=V>)

In addition, a master/PhD course was implemented in 2015 at the University Centre In Svalbard, through partial funding from EWMA II. (AT333/833 <https://www.unis.no/course/at-333-arctic-petroleum-challenges-for-society-technology-and-environment/>)

#### **Publications:**

1. Vieweg I, Benedetti M, Lanzoni I, Regoli F, Nahrgang J (2017) Antioxidant defenses in polar cod (*Boreogadus saida*) and responsiveness towards dietary crude oil exposure. *Marine Environmental Research*, [doi.org/10.1016/j.marenvres.2017.06.005](https://doi.org/10.1016/j.marenvres.2017.06.005)
2. Nahrgang J, Dubourg P, Frantzen M, Storch D, Dahlke F, Meador J. (2016) Corrigendum to “Early life stages of an Arctic keystone species (*Boreogadus saida*) show high sensitivity to a water-soluble fraction of crude oil ». *Environmental Pollution*, [doi.org/10.1016/j.envpol.2016.12.062](https://doi.org/10.1016/j.envpol.2016.12.062)
3. Nahrgang J, Dubourg P, Frantzen M, Storch D, Dahlke F, Meador J. (2016) Early life stages of an Arctic keystone species (*Boreogadus saida*) show high sensitivity to a water-soluble fraction of crude oil. *Environmental Pollution* doi:10.1016/j.envpol.2016.07.044.
4. Bender ML, Frantzen M, Vieweg I, Falk-Petersen IB, Johnsen HK, Rudolfson G, Tollefsen KE, Dubourg P., Nahrgang J (2016) Effects of chronic dietary petroleum exposure on reproductive

development in polar cod (*Boreogadus saida*). Aquatic Toxicology  
doi:10.1016/j.aquatox.2016.10.005

5. Sagerup K, Nahrgang J, Frantzen M, et al. (2016) Biological effects of marine diesel oil exposure in red king crab (*Paralithodes camtschaticus*) assessed through a water and foodborne exposure experiment. *Marine Environmental Research* 119: 126-135.
6. Frantzen M, Regoli F, Ambrose WG, Nahrgang J, Geraudie P, Benedetti M, Locke W, Camus L. Biological effects of mechanically and chemically dispersed oil on the Icelandic scallop (*Chlamys islandica*). *Ecotoxicology and Environmental Safety*, doi: 10.1016/j.ecoenv.2016.01.011
7. Nahrgang J, Korshunova E, Murzina SA, Delmas O, Nemova NN, Berge J (2015) Aspects of reproductive biology of wild caught polar cod (*Boreogadus saida*) from Svalbard waters. *Polar Biology*, doi: 10.1007/s00300-015-1837-2.
8. Bakke M, Nahrgang J, Ingebrigtsen KI, (2015) Comparative absorption and tissue distribution of <sup>14</sup>C-benzo(a)pyrene and <sup>14</sup>C-phenantrene in the polar cod (*Boreogadus saida*) following oral administration. *Polar Biology*, doi: 10.1007/s00300-015-1816-7
9. Berge J, Cottier F, Darnis G, Falk-Petersen S, Gabrielsen T, Johnsen G, Last K, Leu E, Lønne OJ, Moline M, Nahrgang J, Renaud PE, Seuthe L, Søreide J, Varpe Ø, Weslawski JM (2015) In the dark: paradigms of Arctic ecosystems during polar night challenged by new understanding. *Progr Oceanogr*. <http://dx.doi.org/10.1016/j.pcean.2015.08.005>
10. Nahrgang J, Varpe Ø, Korshunova E, Murzina S, 2014 Gender specific reproductive strategies of an Arctic key species (*Boreogadus saida*) and implications of climate change. *PLOS One* doi: 10.1371/journal.pone.0098452.

#### **Proposals funded in the period:**

1. Project leader of COOPENOR “Combined effects Of Petroleum and the Environment in bivalves from the Norwegian-Russian Arctic” from the Norwegian Research Council and the Russian Foundation for Basic Research (kr 11.580.000,-), 2013-2016.
2. Project leader of POLARISATION “Polar cod, lipid metabolism and disruption by PAHs” from the Norwegian Research Council, FRIPRO programme/Universitetsløfte (kr 15.800.000,-), 2012-2015.
3. Research grant (300.000,-) 2014. Fram Centre Flagship “Hazardous substances”, 2014.
4. BIVARC workshop “Collaboration on Arctic bivalves” from the Norwegian Research Council and the Svalbard Science Forum (230.000,-), 2013.

**Full name:** Juho Junttila  
**Employment category:** Postdoc  
**Employment period:** July 2010-June 2013  
**Employer:** Department of Geosciences, UiT The Arctic University of Norway in Tromsø  
**EWMA WP:** EWMA I WP2 Deposition of drill cuttings in the Barents Sea  
**WP-leader:** Juho Junttila  
**EWMA II:** Researcher, WP Leader WP2 Deposition of drill cuttings and mine tailing

### Publications

7. Dijkstra, N., **Junttila, J.**, Skirbekk, K., Carroll, J., Husum, K., Hald, M., 2017. Benthic foraminifera as bio-indicators of chemical and physical stressors in Hammerfest harbor (Northern Norway). *Marine Pollution Bulletin*, 114, 384-396.
8. **Junttila, J.**, Carroll, J., Dijkstra, N., 2015. Variability of present and past PAH concentrations in sediments of the SW Barents Sea. *Norwegian Journal of Geology* 95, 191–210.
9. Dijkstra, N., **Junttila, J.**, Husum, K., Carroll, J., Hald, M., 2015. Natural variability of benthic foraminiferal assemblages and metal concentrations during the last 150 years in the Ingøydjupet trough, SW Barents Sea. *Marine Micropaleontology* 121, 16-31.
10. **Junttila, J.**, Carroll, J., Husum, K., Dijkstra, N., 2014. Sediment transport and deposition in the Ingøydjupet trough, SW Barents Sea. *Continental Shelf Research*, Vol. 76, pp. 53-63.
11. Dijkstra, N., **Junttila, J.**, Carroll, J., Husum, K., Hald, M., Elvebakk, G., Godtliebsen, F., 2013. Baseline benthic foraminiferal assemblages and habitat conditions in a sub-Arctic region of increasing petroleum development. *Marine Environmental Research*, Vol. 92, pp. 178-196.

### Selected presentations related to EWMA

1. Junttila, J., Dijkstra, N., Carroll, J., Husum, K., 2014. Ocean current transportation of sediments and heavy metals in Ingøydjupet, SW Barents Sea. *Arctic Frontiers* 2014.
2. Junttila, J., Carroll, J., Husum, K., Dijkstra, N., 2013. Sediment accumulation areas and sediment transportation in Ingøydjupet, SW Barents Sea. *AMGG* 2013.
3. Junttila, J., Dijkstra, N., Carroll, J., Hald, M., 2012. Anthropogenic pollutants in surface sediments of SW Barents Sea. 30<sup>th</sup> Nordic Geological Winter Meeting, 9-12.1.2012, Reykjavik, Iceland. Abstract pp. 99.

For full overview of publications and presentations visit:

<https://wo.cristin.no/as/WebObjects/cristin.woa/wa/fres?sort=ar&pnr=53697&la=no&action=sok>

### Scientific description:

A baseline characterization of sediment properties and polycyclic aromatic hydrocarbons (PAHs) of the Ingøydjupet trough and Tromsøflaket were studied. This was done in order to investigate the sediment transport and deposition by ocean currents to provide insight into the levels and origins of PAHs in a region with petroleum activities in the SW Barents Sea.

Sedimentation rates decrease with distance offshore. Stronger and more variable bottom currents associated with the Norwegian coastal current operate nearshore based on the down-core distribution of sortable silt (SS) and sediment fractions (clay and silt). The most stable bottom

currents are associated with the northern Ingøydjupet trough which is under the influence of the North Atlantic Current.

The PAH concentrations are of background (Level I) to good level (Level II) based on the Water Framework Directive classification. The average values were found to be higher than have been reported in previous studies. PAHs in surface samples are mainly of pyrogenic or mixed pyrogenic and petrogenic origin. The observed changes in PAH contents in surface and subsurface sediments vary in accordance with changes in grain size and total organic carbon content. In turn, these sedimentary parameters are naturally controlled by the inflow of Atlantic Water and the strength of the two predominating current systems in this region: the North Atlantic Current and Norwegian Coastal Current.

These baseline findings are of relevance for the petroleum industry in planning environmental assessment and monitoring programs connected to the future expansion of industry activities in this region.

**Full name:** Kari Skirbekk  
**Employment category:** Post-doctoral research fellow  
**Employment period:** 01.02.2015-25.07.17  
**Employer:** Department of Geosciences, UiT  
**EWMA WP:** EWMA II WP2 Deposition of drill cuttings and mine tailing  
**WP-leader:** Juho Junttila

#### Publications

1. Pedersen, K.B., Jensen, P.E., Sternal, B., Ottosen, L.M., Henning, M.V., Kudahl, M.M., Junttila, J., Skirbekk, K., Frantzen, M., 2017. Long term dispersion and availability of metals from submarine mine tailings disposal in a fjord in Arctic Norway. *Environmental Science and Pollution Research*. DOI:10.1007/s11356-017-9276-y
2. Sternal, B., Junttila, J., Skirbekk, K., Forwick, M., Carroll, J., Pedersen, K.B., 2017. The impact of submarine copper mine tailing disposal in the 1970s on an Arctic fjord. *Marine Pollution Bulletin*, 120, 136-153.
3. Dijkstra, N., Junttila, J., Skirbekk, K., Carroll, J., Husum, K., Hald, M., 2017. Benthic foraminifera as bio-indicators of chemical and physical stressors in Hammerfest harbor (Northern Norway). *Marine Pollution Bulletin*, 114, 384-396.
4. Skirbekk, K., Junttila, J., Sternal, B., Pedersen, K. B., Forwick, M., Carroll, J., in prep. The impact of past submarine tailing deposition on benthic foraminifera, Repparfjorden, Norway.

#### Outreach/Media

1. 2016 Intervju på forskningsraadet.no "Kampen om Repparfjorden" (02.02.2016)  
[https://www.forskningsradet.no/prognett-nordsatsing/Nyheter/Kampen\\_om\\_Repparfjorden/1254015840545/p1228296261516](https://www.forskningsradet.no/prognett-nordsatsing/Nyheter/Kampen_om_Repparfjorden/1254015840545/p1228296261516)
2. 2016 Intervju i High North News "Vil tette kunnskapshull om sjødeponi" (24.04.2016)  
<http://www.highnorthnews.com/vil-tette-kunnskapshull-om-sjodeponi/>

3. 2016 Intervju i Fiskeribladet Fiskaren "Forsker på konsekvenser om sjødeponi" (01.05.2016)  
<https://fiskeribladet.no/nyheter/?artikkel=46724>

#### Posters and talks

1. Skirbekk, K., Sternal, B., Junttila, J., Forwick, M., 2016 Waste management of mine tailings in a vulnerable Arctic environment (EWMA project). Japan-Norway Science and Innovation week, Tokyo 2016. Abstract. Oral Presentation (Invited speaker).
2. Skirbekk, K., Sternal, B., Junttila, J., Bondo Pedersen, K., Forwick, M., 2016. Physical stability and environmental impact of submarine mine tailings deposited in Repparfjorden, 1972-1978. Geonor møte 2016. Abstract. Oral presentation.
3. Skirbekk, K., Sternal, B., Junttila, J., Forwick, M., 2016 Sub-marine waste deposits in Repparfjorden. Past and Future. Arctic Frontiers side event for NORDSATSNING initiative, Tromsø 2016. Oral Presentation (Invited speaker).
4. Skirbekk, K., Dijkstra, N., Junttila, J., Sternal, B., Bondo Pedersen, K., Forwick, M., Carroll, J.L., 2016. Biomonitoring polluted sediments in the Arctic regions - Possibilities and challenges of using benthic foraminifera. Case studies from northern Norway. EGU 2016. Abstract. Poster presentation.
5. Sternal, B., Junttila, J., Bondo Pedersen, K., Skirbekk, K., Forwick, M., Carroll, J.L., 2016. Sedimentological and geochemical record of submarine mine tailing footprint in Repparfjorden (Northern Norway). EGU 2016. Abstract. Poster presentation.
6. B. Pedersen, K., Sternal, B., Junttila, J., Frantzen, M., Skirbekk, K., 2016. Submarine mine tailings disposal in Repparfjorden, northern Norway – long-term dispersion and availability of Cu. Artek Event 2016. Abstract. Poster presentation.
7. Junttila, J., Skirbekk, K., Sternal, B., Forwick, M., Carroll, J., 2016. Environmental impact of mine tailings deposited in Repparfjorden, Finnmark – Preliminary results. Arctic Frontiers 2016. Abstract. Poster presentation.

#### Research

The objective of this postdoc position has been to investigate how benthic foraminifera respond to contamination from mine tailings in Repparfjorden, Finnmark. A long term goal is to develop a biomonitoring tool for coastal areas in the High North. The research was done in close collaboration with post doctor Beata Sternal, who did a high resolution study on vertical and lateral distribution of mine tailings on the same samples, in order to investigate spreading of sub-marine tailings deposition performed between 1972-1978. Analysis on grain size distributions and heavy metal contents were coupled with faunal distributions of benthic foraminifera in order to study the effects of these stress factors.

Living (upper 5 cm and dead (0-20 cm) fauna of benthic foraminifera from Repparfjorden sediment cores were studied. A distinct difference in faunal composition were observed between the inner and outer fjord, regardless of contamination. This demonstrates the complexity of benthic foraminiferal distribution in high latitude coastal areas. Within the contaminated inner fjord, distinct variation in faunal composition occurred at three different levels of copper contamination; one in uncontaminated samples; one when copper contents in the sediments exceeded  $\sim 350 \text{ mg kg}^{-1}$  and one when copper contents exceeded  $\sim 800 \text{ mg kg}^{-1}$ . In the latter category the faunal composition were dominated by epifaunal species; species that live on top of the sediment (not within). Possibly, the copper content reached a level where it was difficult for the infaunal species to succeed. These

results indicate that benthic foraminifera appear to be suitable for biomonitoring industrial contamination in high latitude coastal areas, but more data is needed.

An attempt to measure uptake of copper into the tests of benthic foraminifera were done by using a table top SEM (scanning electron microscope) with an EDS (energy dispersive detector). The idea was to evaluate if copper uptake into foraminifera reflected contamination levels in the sediments. This could both give an indication on contamination uptake into the marine food chain and serve as an easy method to measure contamination. Five specimens of four different species living in various contamination levels were analysed. The method did however not give any significant result, likely because of to low sensitivity of the EDS detector.

Finally, there was an initiative together with project leader Stian Røberg, where two profiling current meters were placed in Repparfjorden for three months (December-March). This was done in order to get a better constrain on the current regime in Repparfjorden in the area where mine tailings are planned to be deposited in the future. This data will give a better basis for modelling particle spreading from the planned deposition site.

**Full name:** Kristine Bondo Pedersen  
**Employment category:** *PhD* (EWMAI) and *Postdoc* (EWMAII)  
**Employment period:** *PhD* 30.06.10-13.03.15 (reduced position); *Postdoc* 11.05.15-11.05.17  
**Employer:** *PhD* UiT – The Arctic University of Norway; *Postdoc* Akvaplan-niva AS  
**EWMA WP:** EWMA WP: *PhD* EWMA I WP3; *Postdoc* EWMA II WP1  
**WP-leader:** EWMA I; Tore Lejon UiT. EWMA II; Marianne Frantzen APN

**Title of dissertation:** Applying Multivariate Analysis to Developing Electrodialytic Remediation of Harbour Sediments from Arctic Locations

Supervisors: *PhD* Tore Lejon (UiT), co-supervisors Pernille E. Jensen (DTU), Lisbeth M. Ottosen (DTU); *Postdoc* Marianne Frantzen, Akvaplan-niva AS

**Outreach – PhD thesis:** <http://forskning.no/miljogifter-skipsfart/2015/08/bruker-strom-fjerne-miljogifter>

#### **Summary of the research and important findings**

The PhD was undertaken in the first phase of EWMA and involved further development of electrokinetic remediation and adaptation to cold climate. The technology was used to optimise the removal of pollutants from contaminated harbour sediments and soil from Arctic locations in Norway, Greenland and NW Russia. An important aspect of the experimental work and data treatment was planning experiments and analysing the results using multivariate statistical analysis. The use of multivariate statistical analysis was a novel approach for designing and optimising remediation, contributing to the development within the field of remediation. Researchers in



Denmark and Portugal have recently began using multivariate analysis for electrokinetic remediation studies.

In the second phase of EWMA (2014-2017) the focus was on the environmental impacts of submarine mine tailings disposal in northern Norway and has included close co-operation with the other work packages in EWMA. The main findings in the postdoc was related to environmental chemistry, primarily related to availability and mobility of metals in mine tailings, the influence of process chemicals on desorption of metals and the potential for optimising extraction of metals from mine tailings prior to the discharge into fjords. Amongst the important findings was the influence of metal availability on dispersal of metals in fjords. Rather than regarding the total metal concentration, there is a need to consider metal availability when consultants make environmental risk assessments. These aspects are not yet included in the national guidelines for evaluating the environmental risks associated with dispersal of pollutants from polluted materials.

During the postdoc, two small research projects within electrokinetic extraction of metals and phosphorus from waste materials were developed. The first project (2015-2016) was developed and financed by the waste management company, Perpetuum AS and included electrokinetic extraction tests, metal desorption analysis of metal-polluted soil from former shooting range sites. Multivariate analysis was an integrated part of the data interpretation to understand similarities/differences in the shooting range soils as well as to determine optimal settings for remediation. RFF Nord financed a preproject (2016-2017) for evaluating the potential for extracting phosphorus from fish farm sludge and re-using it in the fish farm industry. The results are promising (>90% phosphorous extracted) and a project application for a larger research project is being developed.

### **Scientific publications**

#### **In preparation:**

1. *Pedersen, K.B.; Jensen, P.E.; Ottosen, L.M.; Barlindhaug, J.*: Influence of electrode placement for mobilising and removing metals during electro-dialytic remediation of metals from shooting range soil (submission planned for Chemosphere)
2. *Pedersen, K.B.; Reinardy, H.C; Jensen, P.E.; Ottosen, L.M., Junttila, J., Frantzen, M.*: The influence of Magnafloc10 on the acidic, alkaline, and electro-dialytic desorption of metals from mine tailings (submission planned for Waste Management)
3. *Pedersen, K.B.; Reinardy, H.C; Jensen, P.E.; Ottosen, L.M., Frantzen, M.*: The influence of geochemistry on the desorption of metals from mine tailings
4. *Pedersen, K.B.; Jensen, P.E.; Ottosen, L.M., Kirkelund, G.M.*: Transferring knowledge from sewage sludge to the reuse of fish sludge
5. *Pedersen, K.B.; Jensen, P.E.; Ottosen, L.M., Kirkelund, G.M.*: Multivariate models for predicting removal of phosphorous from fish sludge
6. *Pedersen, K.B.; Jensen, P.E.; Ottosen, L.M., Kirkelund, G.M.*: Influence of experimental variables on the efficiency of electro-dialytic removal of phosphorous from fish sludge
7. *Simonsen, A.M., Pedersen, K.B.; Elberling, B.; Bach, L.*: Applying multivariate analysis to determine dispersion of heavy metals in sediments from Bøkfjorden, Northern Norway

#### **Submitted:**

1. *Pedersen, K.B.; Jensen, P.E.; Ottosen, L.M.; Barlindhaug, J.*: The relative influence of electrokinetic remediation design on the removal of As, Cu, Pb and Sb from shooting range soils (Engineering Geology)

2. *Pedersen, K.B.*; Jensen, P.E.; Ottosen, L.M.; Barlindhaug, J.: Applying multivariate analysis for optimising the electrodialytic removal of Cu and Pb from shooting range soils (Journal of Hazardous Materials)

**Published:**

1. *Pedersen, K.B.*; Lejon, T.; Jensen, P.E.; Ottosen, L.M. The influence of sediment properties and experimental variables on the efficiency of electrodialytic removal of metals from sediment Journal of Chemical Environmental Engineering 5 5312-5321 2017
2. Song, X.; Pettersen, J.B.; *Pedersen, K.B.*; Røberg, S. Comparative life cycle assessment of tailings management and energy scenarios for a copper ore mine: A case study in Northern Norway. Journal of Cleaner Production 164:892-904 2017
3. *Pedersen, K.B.*; Jensen, P.E.; Sternal, B.; Ottosen, L.M.; Henning M.V.; Kudahl, M.M.; Junttila, J.; Skirbekk, K.; Frantzen, M. Long term dispersion and availability of metals from submarine mine tailings disposal in a fjord in Arctic Norway. Environmental Science and Pollution Research 2017
4. Sternal, B.; Junttila, J.; Skirbekk, K.; Forwick, M.; Carroll, J.; *Pedersen, K.B.* The impact of submarine copper mine tailing disposal from the 1970s on Repparfjorden, northern Norway. Marine Pollution Bulletin 120 136-153 2017
5. *Pedersen, K.B.*; Lejon, T.; Jensen, P.E.; Ottosen, L.M. Simultaneous electrodialytic removal of PAH, PCB, TBT and heavy metals from sediments. Journal of Environmental Management 198 192-202 2017
6. *Pedersen, K.B.*; Jensen, P.E.; Ottosen, L.M., Evenset, A.; Christensen, G.N.; Frantzen, M. Metal speciation of historic and new copper mine tailings from Repparfjorden, Northern Norway, before and after acid, base and electrodialytic extraction. Minerals Engineering 107 100-111 2017
7. *Pedersen, K.B.*; Lejon, T.; Jensen, P.E.; Ottosen, L.M. Applying multivariate analysis as decision tool for evaluating sediment-specific remediation strategies, Chemosphere, vol: 151, 59-67, 2016
8. *Pedersen, K.B.*; Lejon, T.; Jensen, P.E.; Ottosen, L.M. Degradation of oil products in a soil from a Russian Barents hot-spot during electrodialytic remediation, Springer Plus, vol: 5, DOI: <http://dx.doi.org/10.1186/s40064-016-1882-5>, 2016.
9. *Pedersen, K.B.*; Ottosen, L.M. ; Jensen, P.E.; Lejon, T., Comparison of 2-compartment, 3-compartment and stack designs for electrodialytic removal of heavy metals from harbour sediments, Electrochimica Acta, vol: 181, pages: 48-57, 2015.
10. *Pedersen, K.B.*; Lejon, T. ; Jensen, P.E.; Ottosen, L.M., Chemometric Analysis for Pollution Source Assessment of Harbour Sediments in Arctic Locations, Water, Air, and Soil Pollution, vol: 226, pages: 1-15, 2015.
11. *Pedersen, K.B.*; Jensen, P.E.; Ottosen, L.M.; Lejon, T., An optimised method for electrodialytic removal of heavy metals from harbour sediments, Electrochimica Acta, vol: 173, pages: 432-439, 2015.
12. Jensen, P.E.; Kirkelund, G.M.; *Pedersen, K.B.*; Dias-Ferreira, C.; Ottosen, L.M., Electrodealytic upgrading of three different municipal solid waste incineration residue types with focus on Cr, Pb, Zn, Mn, Mo, Sb, Se, V, Cl and SO<sub>4</sub>, Electrochimica Acta, vol: 181, pages: 167-178, 2015.

13. *Pedersen, K.B.; Lejon, T.; Ottosen, L.M.; Jensen, P.E.*, Screening of variable importance for optimizing electrodynamic remediation of heavy metals from polluted harbour sediments, *Environmental Technology*, vol: 36, issue: 18, pages: 2364-2373, 2015
14. *Pedersen, K.B.; Kirkelund, G.M.; Ottosen, L.M. ; Jensen, P.E.; Lejon, T.*, Multivariate methods for evaluating the efficiency of electrodynamic removal of heavy metals from polluted harbour sediments, *Journal of Hazardous Materials*, vol: 283, pages: 712-720, 2015.

### Presentations

1. **Arctic Forum 2016, Kirkenes, Norway:** *Pedersen, K.B.* Environmental Waste Management November 2016
2. **MSSCE 2016, Lyngby, Denmark:** *Pedersen, K.B.* Electrodynamic remediation of harbour sediments. Oral presentation September 2016
3. **Sustainable Minerals '16, Falmouth, England:** *Pedersen, K.B.; Jensen, P.E.; Ottosen, L.M., Evenset, A.; Christensen, G.N.; Frantzen, M.* Metal speciation of historic and new copper mine tailings from Repparfjorden, Northern Norway, before and after acid, base and electrodynamic extraction. Oral presentation June 2016
4. **ARTEK event 2016, Sisimiut, Greenland:**
5. *Pedersen, K.B.* Chemometric analysis for pollution source assessment of harbor sediments in Arctic locations. Oral presentation March 2016
6. *Pedersen, K.B.; Jensen, P.E.; Sternal, B.; Ottosen, L.M.; Henning M.V.; Kudahl, M.M.; Junntila, J.; Skirbekk, K.; Frantzen, M.* Submarine mine tailings disposal in Repparfjorden, northern Norway – long-term dispersion and availability of Cu. Oral presentation March 2016
7. Invited speaker to **Arctic Frontiers 2016 - Side events Forskningsløft i nord, Tromsø, Norway:** Environmental Waste Management - Mine tailings in Repparfjorden – Availability of Metals. Presented January 2016

### Symposia on Electrokinetic Remediation (EREM) 2014:

8. *Pedersen, K.B.; Lejon, T.; Ottosen, L.M.; Jensen, P.E.:* Multivariate Analysis of Variable Importance in the Scaling Up of Electrodynamic Removal of Heavy Metals from Harbour Sediments, oral presentation 09.09.14.
9. *Pedersen, K.B.; Lejon, T.; Ottosen, L.M.; Jensen, P.E.:* Electrodynamic removal of heavy metals from harbour sediments Comparative importance of variables in a 2-compartment cell set-up, poster.
10. **The International Symposium on Sediment Management (I2SM) 2014:** *Pedersen, K.B.; Lejon, T.; Ottosen, L.M.; Jensen, P.E.:* Screening of Variable Importance for Optimising Electrodynamic Removal of Heavy Metals from Polluted Harbour Sediments, oral presentation 18.09.14.
11. **Symposia on Electrokinetic Remediation (EREM) 2013:** *Pedersen, K.B.; Kirkelund, G.M.; Ottosen, L.M. ; Jensen, P.E.; Lejon, T.* Multivariate Analysis of Electrodynamic Remediation of Polluted Harbour Sediments, oral presentation 25.06.2013.
12. Invited speaker for internal DNV/Statoil seminar '**Arctic Competence Escalator, workshop 2.1' 2013:** Waste management, presented 19.09.2013.
13. Invited speaker to **Barents Spektakel 2012:** Environmental Management of Industrial Waste in the High North: Electrochemical Remediation of Polluted Sediments in the Arctic, presented 10.02.2012.

14. Invited speaker to **The Norwegian Research Council Northern Areas Conference 2011:**  
Mobile remediation of remediated sediments – developing an industrial research project (in Norwegian) Presented 14.11.2011.

### **Teaching:**

#### **Lectures in courses at The Arctic Technology Centre, DTU:**

1. PhD course 'Electrokinetics in Civil and Environmental Engineering'; lecture 'Electrodialytic remediation of organic pollutions from soil and sediment' 04.05.2017.
2. Course 11859 'Environmental Technology in the Arctic'; Lectures on environmental site assessments and remediation in Arctic regions given in Sisimiut, Greenland, winter 2016, 2017.
3. [http://www.forskningsradet.no/prognett-nordsatsing/Nyheter/Underviste\\_om\\_arktisk\\_forurensing\\_pa\\_Gronland/1254019261364?lang=no](http://www.forskningsradet.no/prognett-nordsatsing/Nyheter/Underviste_om_arktisk_forurensing_pa_Gronland/1254019261364?lang=no)
4. Course 11830 'Mineral resources in the Arctic: Environmental impacts and technologies';  
Online (recorded) lectures on oil spill remediation 2015.

#### **Lectures in courses at UiT – The Arctic University of Norway and UNIS:**

5. AT333/833 'Arctic Petroleum – Challenges for Society, Technology and Environment' Setting up a GC-FID for analysis of PHC and PAH in autumn 2015. Responsible for field and lab work in autumn 2017.
6. AT210 'Arctic Environmental Pollution' Lectures on environmental site assessments, autumn 2017.
7. Bio-3009 'Arctic Marine Pollution' Lectures on metal-polluted sites in Arctic regions, autumn 2016, 2017.
8. Bio-1012 'Fundamentals on Ecotoxicology I' Lectures on environmental risk assessment of metal polluted sites, autumn 2016, 2017.

### **Supervision:**

#### **Bachelor students**

1. Lea Tolstrup Jensen and Kirska Nørregaard 'Electrodialytic Remediation of Heavy Metals and Oil in Harbour Sediment, Sisimiut'
2. Co-supervisor autumn 2015. Main supervisor: Gunvor M. Kirkelund, ARTEK, DTU
3. Manja Marie Kudahl and Mie Vesterskov Henning 'Environmental Investigation of Cu-mine tailings from Northern Norwegian fjord'
4. Co-supervisor spring 2016. Main supervisor: Pernille E. Jensen, ARTEK, DTU

#### **Master student**

5. Anne Mette Tholstrup Simonsen 'Environmental effects of submarine mine tailings disposal in Bøkfjorden, northern Norway'
6. Co-supervisor autumn 2016-spring 2017. Main supervisor: Bo Elberling, Copenhagen University.

**Full name:** Lisa Bjørnsdatter Helgason  
**Employment category:** Post doc  
**Employment period:** April 2011 – September 2014  
**Employer:** UiT, AMB  
**EWMA WP** EWMA I WP1 Biological effects of petroleum related compounds on sub-Arctic and Arctic marine organisms  
**WP-leader:** Paul Wassmann

### Publications

1. L.B. Helgason, H. Wolkers, E. Fuglei, O. Ahlstrøm, E.H. Jørgensen. 2013. Seasonal emaciation causes tissue redistribution and an increased potential for toxicity of lipophilic pollutants in farmed arctic fox (*Vulpes lagopus*). *Environmental Toxicology and Chemistry* 32: 1784-1792.
2. J. Verreault, L.B. Helgason, G.W. Gabrielsen, M. Dam, B.M. Braune. 2013. Contrasting retinoid and thyroid hormone status in differentially-contaminated northern fulmar colonies from the Canadian Arctic, Svalbard and the Faroe Islands. *Environmental International* 52: 29-40.
3. H. Routti, L.B. Helgason, A. Arukwe, H. Wolkers, E.S. Heimstad, M. Harju, V. Berg, G.W. Gabrielsen. 2013. Effects on contaminant exposure and fasting on PCB biotransformation in herring gull (*Larus argentatus*) chicks. *Environmental Toxicology and Chemistry* 32: 156-164.
4. T.H. Nøst, L.B. Helgason, M. Harju, E.S. Heimstad, G.W. Gabrielsen, B.M. Jenssen. 2012. Halogenated organic contaminants and their correlations with circulating thyroid hormones in developing Arctic seabirds. *Science of the total environment* 414: 248-256.

Lectures in courses:

Development of Bio-2008

Lectures in Bio-3001

**Full name:** **Melania Borit**  
**Employment category:** PhD EWMA I and PostDoc EWMA II  
**Employment period:** May 2010 - November 2016  
**Employer:** **UiT NFH**  
**EWMA WP:** **EWMA I WP5, EWMAII WP1**  
**WP-leader:** **EWMA I Petter Holm UiT, EWMA II Marianne Frantzen APN.**

**Title of dissertation:** Trust and traceability. Using culturally tailored environmental risk communication and transparency as trust-building tools.



**Supervisors:** Petter Holm (UiT), Petter Olsen (Nofima)

As a consequence of the controversies around extending petroleum activities in the Lofoten-Vesterålen area and in the Arctic, the trust of the Norwegian public in the petroleum industry is falling down, especially when it comes to trusting the industry's environmental discourse. The present study suggests solutions to overcoming this trust problem. Having complexity science as underlying theory, this research builds up on the ideas that: a) risk communication is more effective if it adapts to the culture of the audience, and b) traceability is a good tool for trust-building. This study advances a new theory about how cognitive trust-building processes (CTBPs) are invoked in humans based on cultural belonging. Using a numerical model of the formalized links between four cultural dimensions and CTBPs, the sequence for invoking CTBPs is calculated. This model can be used by risk communicators as a tool to culturally customize their discourse. Considering petroleum non-hazardous production waste (e.g. drill cuttings) as products, traceability could be implemented in their management system. This study gives an overview of relevant traceability definitions. By combining their best parts, a new possible definition that can potentially be applied to any product is proposed. By analysing the EU legal framework, this research provides theoretical guidelines for implementation of product traceability in any industrial chain. This research has multidisciplinary application, covering international organizational management, organisational behaviour, social psychology, industrial logistics, and the design of socially believable virtual agents in multiagent systems.

#### **Peer-reviewed publications in scientific journals:**

1. Melania Borit, Jorge Santos (2015). Getting traceability right, from fish to advanced bio-technological products: a review of legislation. *Journal of Cleaner Production* (104): 13-22.
2. Petter Olsen, Melania Borit (2013). How to define traceability. *Trends in Food Science & Technology* 29 (2): 142–150.

#### **Book chapters:**

1. Melania Borit (2016). Legal requirements for food traceability in the European Union. *Advances in Food Traceability Techniques and Technologies* (ed. Espiñeira & Santaclara). Woodhead Publishing

**Peer-reviewed full papers with presentations:**

1. Melania Borit, Loïs Vanhée, Petter Olsen (2014). Towards enhancing trustworthiness of socially interactive and culture aware robots. Culture Aware Robotics Workshop (CARs), the 13th International Conference on Autonomous Agents and Multiagent Systems (AAMAS), Paris, France.
2. Melania Borit, Loïs Vanhée, Petter Olsen (2014). Understanding the Impact of Culture on Cognitive Trust-Building Processes: How to Increase the Social Influence of Virtual Autonomous Agents. International Workshop on Trust in Agent Societies (TRUST), the 13th International Conference on Autonomous Agents and Multiagent Systems (AAMAS), Paris, France.
3. Melania Borit, Loïs Vanhée, Petter Olsen (2013). Theoretical Considerations for Enhancing Social Believability through Integrating Culturally Specific Trust-Building Cognitive Features in Non-Playing Characters. Social Believability in Games Workshop (SBGW), the 10th Conference for Advances in Computer Entertainment (ACE), Twente, The Netherlands.

**Peer-reviewed abstracts with presentations:**

1. Melania Borit, Petter Olsen, Jorge Santos (2016) How to use product traceability for documentation of environmental sustainability in mineral production, Northern Regions Geological Resources Conference (GeoNor), Mo i Rana, Norway.

**Posters:**

1. Melania Borit, Michela Aschan, Kåre Nolde Nielsen, Petter Holm (2014). *How national culture may influence fishers' participation in fisheries management and their probability of providing trustworthy documentation*. Second Symposium on Fishery-Dependent Information, Rome, Italy.

**In preparation:**

1. Petter Olsen, Melania Borit, The components of food traceability systems (Trends in Food Science and Technology)
2. Melania Borit, Michaela Aschan - How societal culture may influence the success of proposed solutions for rebuilding fish stocks (Fish and Fisheries)
3. Melania Borit, Loïs Vanhée – Impact of national culture on trust building processes (Academy of Management Journal)

**Full name:** Noortje Dijkstra  
**Employment category:** PhD  
**Employment period:** April 2010-April 2013  
**Employer:** UiT IG  
**EWMA WP:** EWMAI WP2 .  
**WP-leader:** Juho Junntila UiT



Title of dissertation

Benthic foraminifera as indicators of natural variability and anthropogenic impact (defended November 2013)

Supervisors: Dr. Juho Junntila, Dr. JoLynn Carroll, Prof. Morten Hald, Dr. Katrine Husum

**For a full overview of publications and presentations see:**

<https://wo.cristin.no/as/WebObjects/cristin.woa/wa/fres?sort=ar&la=no&action=sok&pnr=53778>

#### **Selected scientific publications:**

1. **Dijkstra, Noortje;** Junntila, Juho; Skirbekk, Kari; Carroll, JoLynn; Husum, Katrine; Hald, Morten. Benthic foraminifera as bio-indicators of chemical and physical stressors in Hammerfest harbor (Northern Norway). *Marine Pollution Bulletin* 2017; Volum 114 (1). doi: 10.1016/j.marpolbul.2016.09.053.
2. **Dijkstra, Noortje;** Junntila, Juho; Husum, Katrine; Carroll, JoLynn; Hald, Morten. Natural variability of benthic foraminiferal assemblages and metal concentrations during the last 150 years in the Ingøydjupet trough, SW Barents Sea.. *Marine Micropaleontology* 2015; Volum 121. doi: 10.1016/j.marmicro.2015.09.005.
3. **Dijkstra, Noortje;** Junntila, Juho; Carroll, JoLynn; Husum, Katrine; Hald, Morten; Elvebakk, Georg; Godtliobsen, Fred. Baseline benthic foraminiferal assemblages and habitat conditions in a sub-Arctic region of increasing petroleum development. *Marine Environmental Research* 2013; Volum 92. doi: 10.1016/j.marenvres.2013.09.014.
4. Schönfeld, J., Alve, E., Geslin, E., Jorissen, F., Korsun, S., Spezzaferri, S., Abramovich, S., Almogi-Labin, A., Armynot du Chatelet, E., Barras, C., Bergamin, L., Bicchi, E., Bouchet, V., Cearreta, A., Di Bella, L., **Dijkstra, N.**, Trevisan Disaro, S., Ferraro, L., Frontalini, F., Gennari, G., Golikova, E., Haynert, K., Hess, S., Husum, K., Martins, V., McGann, M., Oron, S., Romano, E., Mello Sousa, S., Tsujimoto, A., 2012, The FOBIMO (Foraminiferal Bio-Monitoring) initiative – Towards a standardized protocol for soft-bottom benthic foraminiferal monitoring studies, *Marine Micropaleontology*, 94-95, 1-13. doi: 10.1016/j.marmicro.2012.06.001

#### **Selected EWMA-related oral presentations:**

1. **Dijkstra, N.**, Monitoring the environment: the importance of pre-impact baselines. MAREANO conference 2015, Oslo, Norway. (invited speaker)
2. **Dijkstra, N.**, Junntila, J., Husum, K., Carroll, JL., Hald, M., 2015. Natural variability of benthic foraminiferal assemblages and metal concentrations in the Ingøydjupet trough, SW Barents Sea. Arctic Workshop 2015, 10-13 May 2015, Bergen, Norway. Abstract pp. 112.



3. **Dijkstra, N.**, Junttila, J., Husum, K., Carroll, J., Klitgaard-Kristensen, D. and Hald, M., 2012. Benthic foraminifera as indicators of pollution in high latitude marine environments. European Geoscience Union General Assembly, Vienna, Austria, Geophysical Research Abstracts Vol. 14, EGU 2012-4722, 2012.
4. **Dijkstra, N.**, Junttila, J., Carroll, J., Husum, K., Hald, M., 2012. Using benthic foraminifera as bio indicators of pollution in the SW Barents Sea. 30th Nordic Geological Winter Meeting, 9-12.1.2012, Reykjavik, Iceland. Abstract pp. 99.

**Press release:**

1. Forurensning av Barentshavet overvåkes med mikroorganismer. Press release by UiT regarding PhD dissertation, [https://uit.no/nyheter/artikkel?p\\_document\\_id=358280](https://uit.no/nyheter/artikkel?p_document_id=358280)

**Scientific description:**

Benthic foraminifera (micro-organism living on the sea-floor) were studied in the southwestern Barents Sea and Hammerfest harbor. The study focused on the response of the micro-organisms to natural and manmade environmental changes. The study shows that the southwestern Barents Sea is relatively clean, and the foraminifera are only impacted by natural changes. Benthic foraminifera reflect the environmental baseline of the area. This can be used as a future reference to monitor the long term impact of pollution, for example drill cutting releases, on the Barents Sea seafloor environment. In the Hammerfest harbor, pollution had severe impact on the organisms. Benthic foraminifera accurately reflected the different pollution sources active in the harbor, including high heavy metal concentrations, organic matter enrichment and physical disturbances by ship propellers. Understanding the response of the foraminifera to different types of environmental changes can be used to develop a bio-monitoring tool. Such a bio-monitoring tool based on foraminifera helps to register environment impact rapidly. Because of the expected increase in industrial activities in the Arctic, and consequently the potential for increased industrial discharges into the marine environment, such a bio-monitoring tool is expected to be important for the region.

**Name: Xingqiang Song**

**Employment category:** Postdoc

**Employment period:** 2016-01-01 to 2017-06-30

**Place of employment:** The Arctic University of Norway (UiT), Tromsø

**Title of dissertation/work:** Life cycle assessment (LCA) of tailings and energy management in the mining industry

**Summary of research and important findings:**

The LCA postdoc work focuses mainly on two research topics: (1) comparison of life cycle environmental impacts of tailings disposal and energy scenarios for a Norwegian copper ore mine (Nussir), and (2) identification of challenges and research needs for life cycle impact assessment in the Arctic.

The main findings from the study on LCA of the Nussir copper mining case study are summarized as follows. Firstly, a detailed life cycle inventory of the copper ore mine is provided, serving as a basis for benchmarking with other mines as well as for updating future mining LCA database. Secondly, a

geochemical approach, based on sequential extraction, is demonstrated to estimate the metal leaching potential of tailings, which could aid in addressing a particular challenge in assessing the toxicity and ecotoxicity impacts of heavy metal leaching from tailings in mining LCAs. Thirdly, this study is the first attempt in the literature to compare the potential life cycle environmental impacts of tailings before and after electro-dialytic remediation. Results of the comparative LCA study show a trade-off between the benefits of electro-dialytic tailings remediation (extracting more copper) and the potential impacts of deposited tailings after electro-dialysis (changes of metal mobility of tailings), indicating the necessity of incorporating different perspective to support the development of more proactive tailings management strategies.

With regard to the research on life cycle impact assessment (LCIA) in the Arctic, our study shows that significant research gaps remain in Arctic-dependent LCIA. In particular, the following two aspects need further attention: (1) the possible influences of the Arctic specific features (e.g. seasonality, cold climate, and marine dependency) on characterization factors for impact assessment in LCA, and (2) the coverage of impact pathways, especially on the under-addressed marine environment and near-shore processes. This study calls for further development of site dependent Arctic LCA, which could increase the credibility of LCA as an environmental decision-support tool for Arctic industrial activities, facilitate better communication among stakeholders, and support sustainable Arctic development.

#### **Refereed Journal Articles**

1. Song, X., Pettersen, J.B., Pedersen, K.B., Røberg, S., 2017. Comparative life cycle assessment of tailings management and energy scenarios for a copper ore mine: A case study in Northern Norway. *Journal of Cleaner Production*, 164, 892-904.  
<https://doi.org/10.1016/j.jclepro.2017.07.021>
2. Pettersen, J.B., Song, X., 2017. Life cycle impact assessment in the Arctic: Challenges and research needs. *Sustainability*, 9(9), 1605. doi:10.3390/su9091605

#### **In preparation:**

1. Song, X., Pedersen, K.B., Pettersen, J.B., Røberg, S. 2018. Environmental assessment of Electrokinetic Remediation of a Lead-Contaminated Shooting Range Site: Life Cycle Assessment of In-Situ and Ex-Situ alternatives.

#### **Submitted:**

2. Song, X., Liu, Y., Pettersen, J.B., Ma, X., Røberg, S., Sun, G., Frostell, B., 2017. Environmental impact assessment of recirculating aquaculture systems using life cycle assessment: A case of land-based Atlantic salmon farming in China. Manuscript submitted to *Aquaculture*.

#### **Presentations:**

1. Song, X., Pettersen, J.B. 2018. Life cycle assessment of subsea copper tailings disposal. Presentation at Arctic Frontiers 2018, 21-26 January 2018, Tromsø.
2. Pettersen, J.B., Song, X., 2017. Arctic life cycle impact assessment – gaps in high-north LCA. Poster presentation at the 8th International Conference on Life Cycle Management, 3-6 September 2017, Luxembourg.
3. Pettersen, J.B., Song, X., 2016. Life Cycle Assessment and Governance: The Case of the High North. Presentation at the SMART Conference “Life-cycle based management and reporting for sustainable businesses”, 29-30 November 2016, Oslo.

- Song, X., 2016. LCA and its application in assessing the environmental impacts of aquaculture production: progress and challenges. Presentation at “The 5th conference on Aquaculture Development and Industrialization”, 22-24 October 2016, Dalian, China.

**Full name:** Yonas Sewdu Ayele  
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**Employer:** UiT Department of Engineering and Safety  
**EWMA WP:** EWMA I WP8  
**WP-leader:** Javad Barabady UiT

**Title of dissertation:** Risk-Based Analysis of Drilling Waste Handling Operations: Bayesian Network, Cost-effectiveness, and Operational Conditions

#### Refereed Journal Articles

- Dynamic model for spare parts transportation for Arctic production facility.* Ayele, Y. Z., Barabadi, A., Barabady, J. International Journal of System Assurance Engineering and Management, In Press 2015. DOI: [10.1007/s13198-015-0379-x](https://doi.org/10.1007/s13198-015-0379-x)
- Dynamic Bayesian network based risk assessment for Arctic offshore drilling waste handling practices.* Ayele, Y. Z., Barabady, J., Droguett, E.L. Journal of Offshore Mechanics and Arctic Engineering-Transactions of The ASME 2016. ISSN 0892-7219.s doi: [10.1115/1.4033713](https://doi.org/10.1115/1.4033713)
- Risk-based cost-effectiveness analysis of waste handling practices in the Arctic offshore operation.* Ayele, Y. Z., Barabadi, A., Droguett, E.L. Journal of Offshore Mechanics and Arctic Engineering-Transactions of The ASME 2016. ISSN 0892-7219.s doi: [10.1115/1.4032707](https://doi.org/10.1115/1.4032707)
- A methodology for identification of suitable drilling waste handling systems in the Arctic region.* Ayele, Y. Z., Barabadi, A., Barabady, J. International Journal of Environment and Waste Management 2016; Volume 17 (3/4). ISSN 1478-9868.s 227 - 250.s doi: <http://dx.doi.org/10.1504/IJEW.2016.078596>
- Risk assessment of Arctic drilling waste management operations based on Bayesian Networks.* Ayele, Y. Z., Barabadi, A., Droguett, E.L. In Proceeding of the European Society for Reliability Annual Meeting (Safety and Reliability of Complex Engineered Systems: ESREL 2015), Zürich, Switzerland. pp. 1907 – 1915, 7 – 10 September 2015

#### Refereed Conference and Workshop Proceedings

- Drilling waste handling practices in low temperature operations: A risk perspective.* Ayele, Y. Z., Løset, S., In Proceedings of the International Conference on Port and Ocean Engineering under Arctic Conditions (POAC15), Trondheim, Norway, June 14 – 18, 2015.
- Losses from failure: RAMS analysis in extreme cold operating conditions.* Amare, G.D., Ayele, Y. Z., Barabady, J. In Proceedings of the International Conference on Port and Ocean Engineering under Arctic Conditions (POAC15), Trondheim, Norway, June 14 – 18, 2015
- Performance-based risk management systems (PBRMS) in the Arctic drilling waste handling operation.* Ayele, Y. Z., Barabadi, A., Barabady, J., In Proceeding of the IEEE International

Conference on Industrial Engineering and Engineering Management (IEEM 2015), Singapore, 6 – 9 December 2015.

4. *Reliability modelling of successive release of software using NHPP*. Barabadi, A., Soleiman, A. H., Lu, J., Yuan, F., Ayele, Y. Z. In Proceeding of the IEEE International Conference on Industrial Engineering and Engineering Management (IEEM 2015), Singapore, 6 – 9 December 2015.
5. *A risk-based approach to manage the occupational hazards in the Arctic drilling waste handling practices*. Ayele, Y. Z., Barabadi, A., Barabady, J. In Proceeding of the European Society for Reliability Annual Meeting (ESREL 2014), Wrocław, Poland. pp. 1329 – 1334, 14 – 18 September 2014. DOI: [10.1201/b17399-183](https://doi.org/10.1201/b17399-183)
6. *Effectiveness assessment for waste management decision-support in the Arctic drilling*. Ayele, Y. Z., Barabadi, A., Barabady, J. In Proceeding of the IEEE International Conference on Industrial Engineering and Engineering Management (IEEM 2014), Kuala Lumpur, Malaysia, 9 – 12 December 2014. pp. 559 – 564. DOI: [10.1109/IEEM.2014.7058700](https://doi.org/10.1109/IEEM.2014.7058700)
7. *Drilling waste handling and management in the High North*. Ayele, Y. Z., Barabadi, A., Barabady, J. In Proceeding of the IEEE International Conference on Industrial Engineering and Engineering Management (IEEM 2013), Bangkok, Thailand, 10 – 13 December 2013. pp. 673 – 678. DOI: [10.1109/IEEM.2013.6962496](https://doi.org/10.1109/IEEM.2013.6962496)

#### **Brief project summary – Scientific**

The aim of this research study is to evaluate, identify, and propose a methodology for drilling waste handling practices by considering the complex and fast-changing nature of the Arctic operational conditions. Moreover, the study seeks to foster an integrated interdisciplinary understanding of technical and operational risks associated with drilling wastes and their management by implementing the risk-based analysis. Furthermore, the study focuses on developing the concept of a dynamic model for spare parts transportation in Arctic conditions. The result of the study shows that working in the cold Arctic environments has the potential if not managed properly to cause a significant negative effect on the cost elements and the risk of events. Moreover, the result from the temporal link or dynamic Bayesian network based risk analysis demonstrates that these negative impacts of the peculiar Arctic risk influencing factors on the reliability of the waste handling system and the risk of marine pollutions, is more significant with time. Furthermore, the dynamic model analysis results demonstrate that the operating environment of the Arctic region increases the spare parts transportation time significantly, particularly, during winter season, when transporting the spare parts from the southwestern part of Norway to northern Norway.

Page link to thesis: <http://munin.uit.no/handle/10037/9481>