Introduction, aim and hypotheses

TREASURE was launched to expedite the remediation of contaminated sites, within the Swedish Geotechnical Institute's TUFFO initiative. In 2014, the Geological Survey of Sweden published a survey of "fiberbanks" along Västernorrland's coast. Fiberbanks are contaminated deposits of cellulose-rich waste that originated from pulp and paper factories (incl. sawmills) prior to regulation. TREASURE aimed to develop and apply methods to assess the risk of contaminant dispersal from fiberbanks, and it included 6 work-packages (coordination, fieldwork, slope stability, chemical & biological, risk assessment, and remediation). The project was a collaboration between universities and government authorities and involved communication with county boards. An international partner was the Center for Marine Environmental Science, Univ. of Bremen. An "industrial" PhD student employed by SGU (A. Apler) was enrolled into the PhD discipline Natural Resources and Sustainable Development at Uppsala Univ.

Materials and methods

SV Ocean Surveyor was used for fieldwork, 1 week in 2014 and 2 in 2015. Two fiberbank deposits (Väja & Sandviken), associated fiber-rich sediments and a reference station in the Ångermanälven estuary were chosen for characterization. A third fiberbank (Kramfors) was studied in less detail because the seabed was too complex for geotechnical aims, but it was targeted for chemistry and biology. Hydro-acoustic surveys were used to design transects for in-situ geotechnical measurements and collection of sediment cores, with the aim to determine the sub-seafloor stratigraphy and slope (in)stability. The cores were used to ground-truth data collected by a free-fall dynamic cone penetrator (CPTu), which provided in-situ depth profiles of parameters such as undrained-shear strength and pore-water pressure.

Sediments were divided into 3 classes: fiberbanks, fiber-rich and natural sediments relatively free of fibers. In-situ benthic landers equipped with incubation chambers were used to establish diffusion rates of metals between the sediment types and the overlying water, and benthic flux-chambers loaded with semi-permeable membrane devices were deployed over several weeks to establish sediment-to-water fluxes of persistent organic pollutants (POPs). Bottom water samples were taken in the field before and after sediment disturbance to study the effect of sudden sediment resuspension on advective dispersal of metals. Laboratory experiments were made on collected sediments to determine pore-water concentrations of bioavailable POPs. Fauna collected from fiber-rich sediments and unaffected sediments included the deposit-feeder Marenzelleria spp. (n = 10) and the predator Saduria entomon (n = 4), which were analyzed for POPs to study bioaccumulation and biomagnification. Eight samples of Marenzelleria were analyzed for methyl mercury (MeHg). A study of sediment microbial genetics was undertaken to assess long-term microbiologically induced degradation of specific POPs. A complete list of samples and measurements undertaken in the project is too extensive to be included in this summary; it will be published in an SGI report.

Results

Väja's fiberbank is most likely thicker (up to 12 m) and more extensive than previously estimated by SGU, while the thickness and extent of the Sandviken fiberbank agrees, within uncertainty, with a previous estimate. Geotechnically, fiberbank deposits are unusual because compared to more mineral-rich sediments they are softer and have a low bulk density. They contain significant volumes of gas due to organic matter decomposition, which was observed to escape through pockmarks (vents) at the Väja site, but was relatively trapped by a thin (approx. 15 cm) layer of mineral-rich sediment at the Sandviken site. Core samples were disturbed by recovery methods and/or decompression, and it was not possible to use accredited laboratory geotechnical tests. The low density and almost buoyant character of the Väja fiberbank deposit means that it is internally stable, while the "chippy" nature of the Sandviken fiberbank precluded a characterization. However, both fiberbanks rest on layers of clays and silts that are prone to failure in area.

The measured sediment concentrations of Pb and Cd exceeded ecotoxicological threshold values at Väja and Sandviken, respectively. The resuspension study revealed that metal contaminants, when detected, increased only in the solid phase, while dissolved concentrations decreased. This difference is likely due to the metals being strongly sorbed to solids, which include both the fibers and clay particles. The benthic flux-chamber study revealed that diffusion alone cannot explain the observed fluxes of metals and that advective dispersal takes place.

Oxygen levels are low (hypoxic) or absent (anoxic) due to the high biological oxygen demand caused by organic matter degradation. Benthic fauna were not observed on the surfaces of the Väja fiberbank, although a few crawling individuals of Saduria entomon were seen on the mineral-rich sediment that overlays the Sandviken fiberbank. Individuals of Marenzelleria spp. were found in fiber-rich sediment and sediments free of fibers. Significantly higher sorption (K_D) of POPs was observed in fiberbanks compared to other sediment types, but the pore water levels were still elevated due to high bulk concentrations. Biota-to-sediment accumulation factors (BSAFs) of 20 PCBs, 6 DDX and HCB exceed 1.6, which indicates that biota have accumulated POPs. BSAFs were higher in the predator and points to biomagnification.

Discussion

Fiberbanks are characterized by high concentrations of organic matter, which lead to hypoxia and anoxia. Organic matter decomposition causes the production, build-up and release of gases (e.g. CH_4 and CO_2), which may facilitate contaminant transport. The gas content creates sediment properties that are challenging to laboratory geotechnical characterization, while in-situ measurements of physical properties are promising, but need refinement. We conclude that the (i) environmental impact of advective processes must be considered in risk assessment of fiber-impacted sediments, (ii) organic pollutants are bioaccumulating and mostly likely biomagnifying and (iii) that Cd and Pb occur in levels in fiberbanks that can be harmful to benthic organisms if they are exposed to them. A probabilistic approach was developed to assess the likelihood of contaminant dispersal by each pathway and hence the potential for contaminants to reach levels that can harm the ecosystem. This approach will provide guidance on the paths of dispersal that need to be managed to fulfill environmental goals. Finally, based on the UN Global Goals an approach was developed to assess the sustainability of measures.

Scientific reports published or submitted at 2019-02-28.

1. Apler, A. 2017. Dispersal and environmental impact of contaminants in organic rich, fibrous sediments of industrial origin in the Baltic Sea. Licentiate thesis, Uppsala University, Department of Earth Sciences. 53pp. urn:nbn:se:uu:diva-349826.
2. Apler, A., Snowball, I., Frogner-kockum, P., & Josefsson, S. 2019. Distribution and dispersal of metals in contaminated fibrous sediments of industrial origin. Chemosphere, 215, 470–481. doi: 10.1016/j.chemosphere.2018.10.010
3. Frogner-Kockum, P. et al. Submitted. Less metal fluxes than expected from fibrous marine sediments. Bulletin of Marine Pollution.
4. Dahlberg, A.K., et al. Submitted. Persistent organic pollutants in wood fiber contaminated sediments from the Baltic Sea. Chemosphere.
5. Snowball, I. et al. C.E. 2019. Pollution from land-based sources. In Techera, E. & Winter, G. (Eds.). Marine Extremes. London: Routledge, 254 pages, doi: 10.4324/9780429491023.

And

SGI, 2019. In prep. TREASURE: Targeting Emerging Contaminated Sediments Along the Uplifting Northern Baltic Coast of Sweden for Remediation: A summary of a four-year TUFFO research project.