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Microbial sulfate reduction in Arctic catchments

Mitigating effects from both long-term acid mine drainage and climate change?

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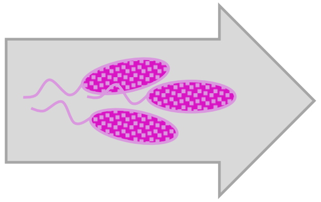
Microbial sulfate reduction (MSR):

Transform sulfate into sulfide through the consumption of organic matter:

Sulfate-reducing microbes

Sulfate SO_4^{2-}



Hydrogen sulfide H_2S

Organic material → CO_2

Occurs in anaerobic environments (lack of oxygen), e.g.:

- Lakes, wetlands
- Groundwater
- Ocean

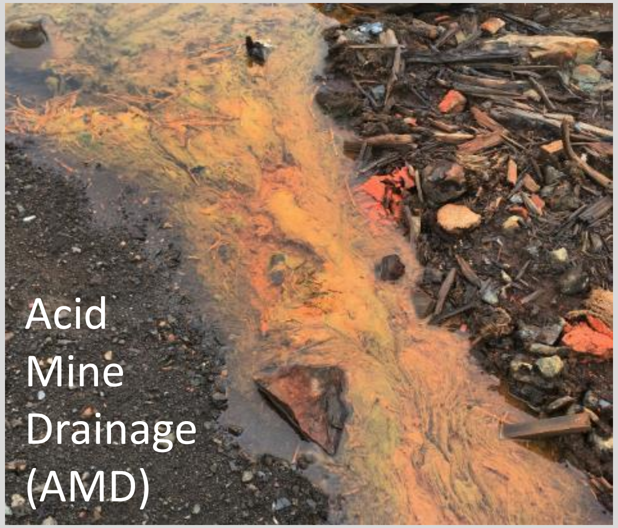
Service 1: Bioremediation tool for wastewater

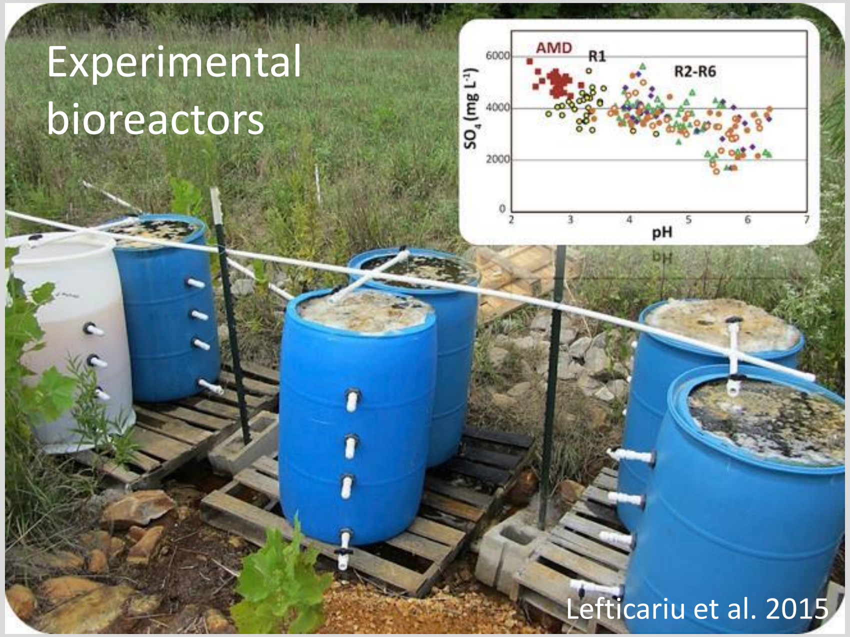
The produced sulfide reacts with dissolved metal ions and form metal sulfide precipitates:

$H_2S \xrightarrow{Zn^{2+}} ZnS$

$H_2S \xrightarrow{Cd^{2+}} CdS$

$H_2S \xrightarrow{Pb^{2+}} PbS$





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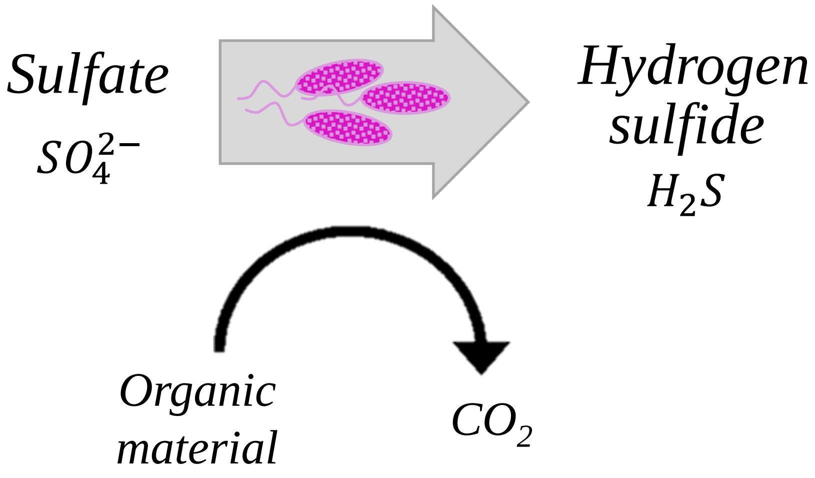

Occurs in anaerobic environments (lack of oxygen), e.g.:

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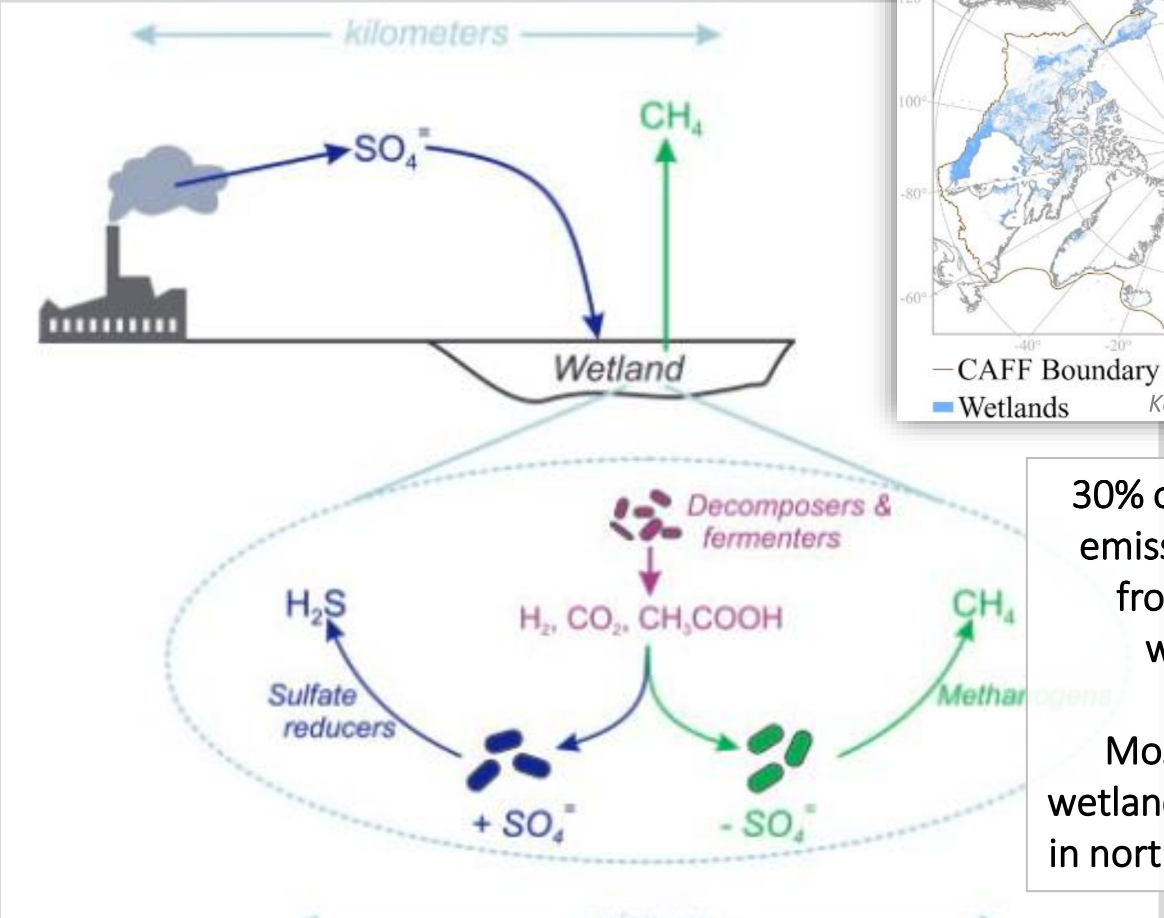
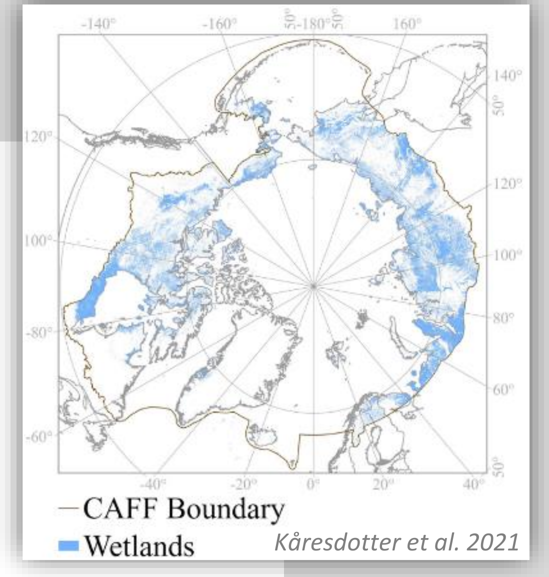
Service 1: Bioremediation tool for wastewater

Service 2: Suppressing methane emissions

Sulfate-reducing microbes can outcompete methane-producing microbes



Schimel 2004



Kåresdotter et al. 2021

30% of global CH_4 emissions comes from natural wetlands

Most of these wetlands are located in northern latitudes

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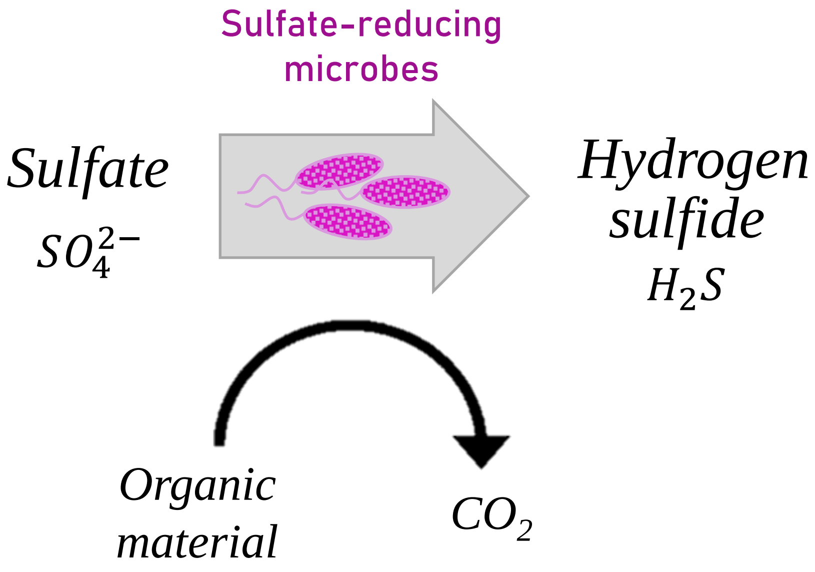

Occurs in anaerobic environments (lack of oxygen), e.g.:

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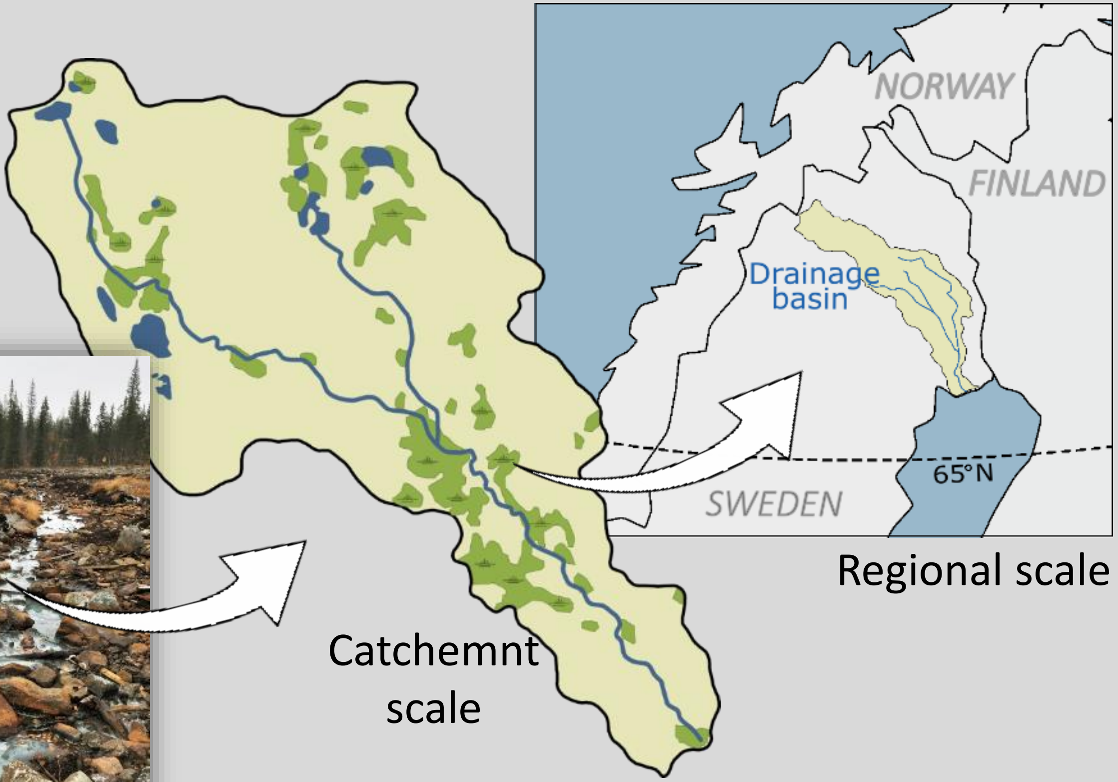
Service 1: Bioremediation tool for wastewater

Service 2: Suppressing methane emissions

Challenge: microbial processes at landscape-scale?

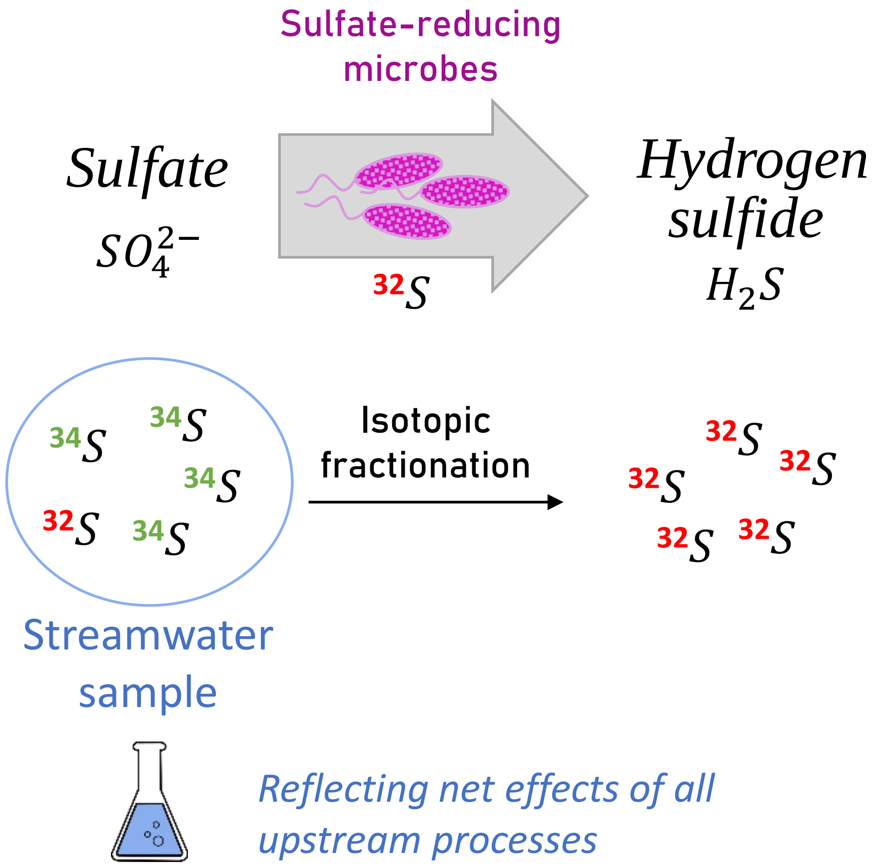


Local scale

What are the dominant processes behind spatio-temporal variability in MSR within and across catchments?

Method: using sulfur isotopes in stream water

Sulfate-reducing microbes preferentially consumes ^{32}S, which leaves the remaining sulfate enriched in ^{34}S:



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Catchment-scale microbial sulfate reduction (MSR) of acid mine drainage (AMD) revealed by sulfur isotopes☆

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ABSTRACT

Laboratory experiments and point observations, for instance in wetlands, have shown evidence that microbial sulfate reduction (MSR) can lower sulfate and toxic metal concentrations in acid mine drainage (AMD). We here hypothesize that MSR can impact the fate of AMD in entire catchments. To test this, we developed a sulfur isotope fractionation and mass-balance method, and applied it at multiple locations in the catchment of an abandoned copper mine (Nautanen, northern Sweden). Results showed that MSR caused considerable, catchment-scale immobilization of sulfur corresponding to a retention of 27 ± 15% under unfrozen conditions in the summer season, with local values ranging between 13 ± 10% and 53 ± 18%. Present evidence of extensive MSR in Nautanen, together with previous evidence of local MSR occurring under many different conditions, suggest that field-scale MSR is most likely important also at other AMD sites, where retention of AMD may be enhanced through nature-based solutions. More generally, the developed isotope fractionation analysis scheme provides a relatively simple tool for quantification of spatio-temporal trends in MSR, answering to the emerging need of pollution control from cumulative anthropogenic pressures in the landscape, where strategies taking advantage of MSR can provide viable options.

1. Introduction

Unmonitored sulfide mine waste carries the risk of century-long, adverse environmental effects due to acid mine drainage (AMD; Doumas et al., 2018). The formation of AMD involves oxidation of sulfide minerals, which results in decreasing pH and release of sulfate and metal ions (Nordstrom et al., 2015). Severe impacts of AMD have been widely documented in the world's mining regions (Barry et al., 2000; Olías et al., 2006). This includes pollution from remotely located historical mines in the Arctic region (Fischer et al., 2020), which is also under pressure from a faster pace of climate change than the world average (Schindler and Smol, 2006).

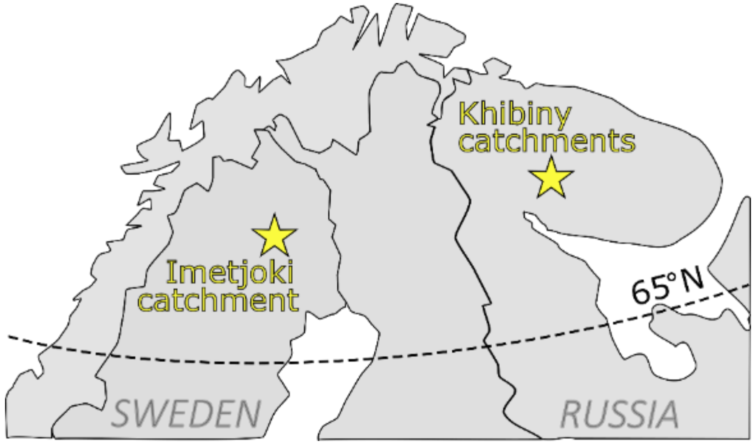
A process that can limit impacts of AMD is microbial (dissimilatory) sulfate reduction (MSR), which occurs in anoxic environments where organic material is available for metabolic degradation, e.g., in wetlands, streambed sediments and aquifers (Knöller et al., 2008; Kümmel et al., 2015; Webb et al., 1998). The microbes (archaea and bacteria) convert sulfate into sulfide (H_2S) which in turn reacts with and immobilizes dissolved (toxic) metals by precipitation into less bioavailable forms (Muyzer and Stams, 2008). Laboratory experiments reproducing conditions in constructed wetlands have demonstrated that MSR potentially can be an important bioremediation technique of AMD (also) in surface waters by showing a metal removal of >95% compared to initial conditions despite prevailing low pH that frequently are harmful to microbes (Jong and Parry, 2003; Xu and Chen, 2020). Similarly, an AMD-impacted wetland in Northern Wales, UK, showed pH-values between 3 and 6 while metal concentrations were still reduced by between 37% and 64%, partly due to MSR (Dean et al., 2013).

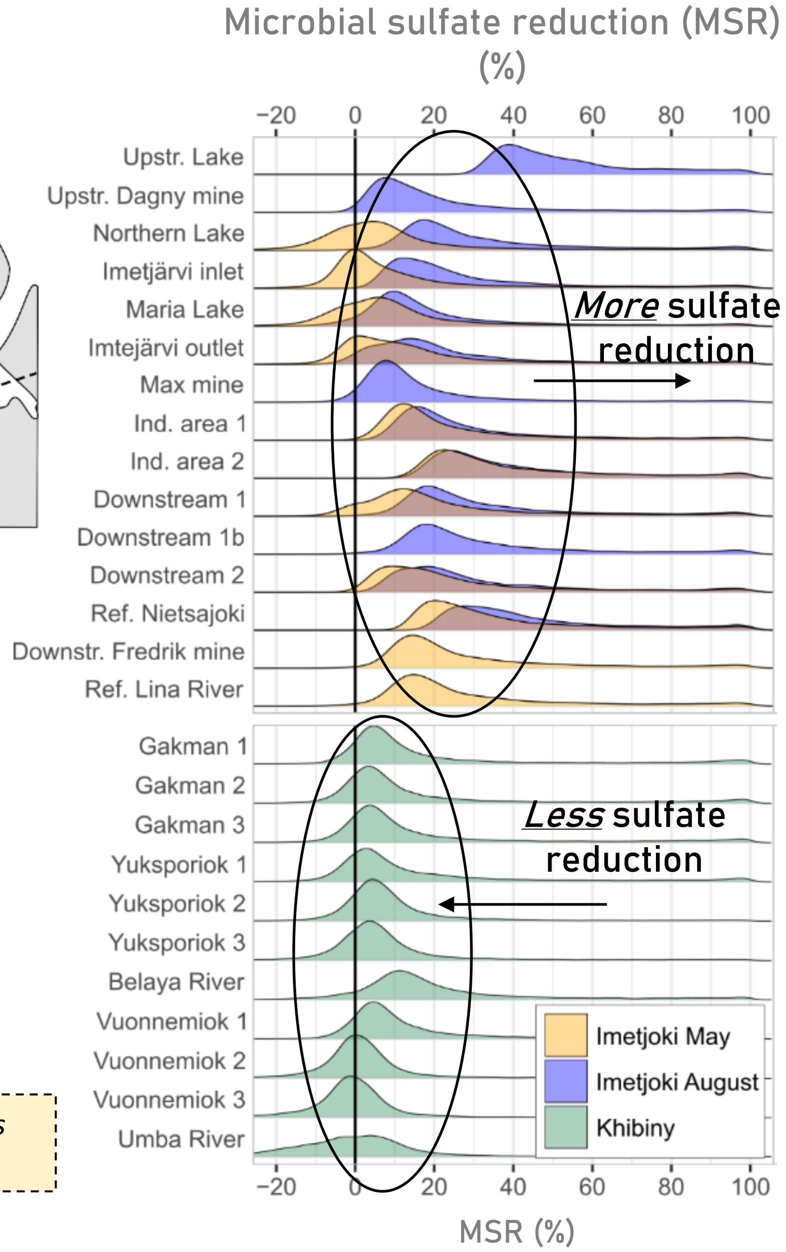
Sulfur isotopes reported as $\delta^{34}S_{SO4}$-values have previously been used to estimate the reduction of sulfate concentration due to MSR in different types of surface waters, e.g., in a wetland (Mandernack et al., 2000), and in a river stretch (Xia et al., 2017). However, favorable conditions for MSR occurring simultaneously in multiple water systems throughout a hydrological catchment, for example in connected groundwater – wetland/lake – stream systems (and thus representing an overall or catchment-scale potential MSR) has not been quantified before. It is therefore unclear to which degree the MSR found on local scales can represent the entire surrounding catchment – the key

Results: local to catchment-scale microbial sulfate reduction

Took water samples from two sites:

- Imetjoki catchment – Sweden
    - Forested, low land
    - Abandoned Cu mines Nautanen
- Khibiny catchments – Russia
    - High alpine tundra
    - Active large-scale apatite mining (PhosAgro)





Findings:

- ***Favorable conditions*** for microbial sulfate reduction seems to include: high organic content (e.g., from forest), longer residence times (e.g. in lakes, wetlands) and neutral pH → Imetjoki catchment
- Combination of ***unfavorable conditions*** (e.g., little organic content, fast residence times, high pH) seems to inhibit microbial activity → Khibiny catchments

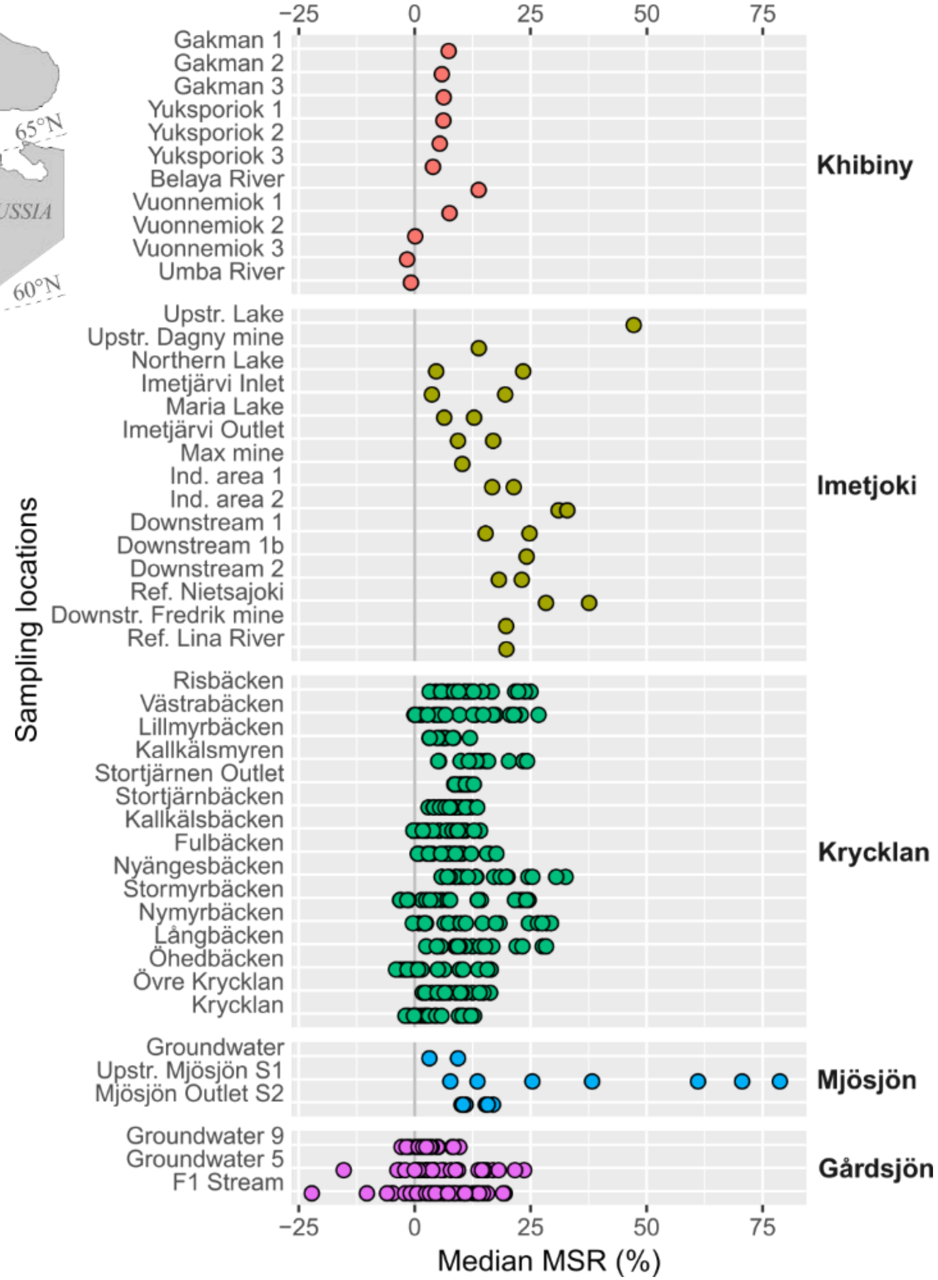
Fischer S, Mörth CM, Rosqvist G, Chalov S, Efimov V, and Jarsjö J [in review]: Microbial sulfate reduction (MSR) as nature-based solution (NBS) to mine drainage: Contrasting spatio-temporal conditions in northern Europe

Results: catchment to landscape-scale?

Synthesized data from 5 catchments with varying spatial characteristics:

- Slope
- Lakes + wetlands
- Forest
- Depth to bedrock

= Representing main drivers of microbial sulfate reduction



Preliminary findings:

- Microbial sulfate reduction is likely wide-spread in the environment
    - Good for long-term management of abandoned mines → nature-based solution for acid mine drainage
- This is not a green-card for extractive industries that it's safe to pollute, it is a call for the ***importance of preserving natural areas*** with lakes and wetlands, especially in northern latitudes, to be able to ***mitigate the already on-going effects*** of such extractive industries, both from pollution the environment and changing the climate

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THANK YOU!

Questions later? Email me at: sandra.fischer@natgeo.su.se

SOURCES

Kåresdotter et al. (2021) Mapping the vulnerability of Arctic wetlands to global warming. *Earth's Future,* 9, e2020EF001858. https://doi.org/10.1029/2020EF001858

Lefticariu et al. (2015) Sulfate reducing bioreactor dependence on organic substrates for remediation of coal-generated acid mine drainage: Field experiments. *Applied Geochemistry* (63) 70-82. https://doi.org/10.1016/j.apgeochem.2015.08.002

Schimel (2004) Playing scales in the methane cycle: From microbial ecology to the globe. *PNAS,* 101 (34) 12400-12401. https://doi-org.ezp.sub.su.se/10.1073/pnas.0405075101

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