ÖSTERSJÖSTIFTELSEN
THE FOUNDATION FOR BALTIC AND EAST EUROPEAN STUDIES

SCIENTIFIC FINAL REPORT
Two- and three-year projects and postdoctoral projects

Registration-number, Östersjöstiftelsen: 77/17

Project manager: Sara Sjöling

Project title: Response and recovery of benthic biodiversity and ecosystem function to chemical pollution and eutrophication

1. The three most important results of the project and what conclusions can be drawn from them

Benthic habitats have a crucial role in the ecosystem functions of nutrient cycling between pelagic waters and sediment. In the Baltic Sea, this ecosystem faces significant pressure due to eutrophication-driven oxygen decline and industrial metal pollution. Essential drivers of nitrogen cycling in the ecosystem are microorganisms. This project focused on better understanding how microbial diversity and microbial nitrogen cycling processes in sea sediment respond to toxic metals and dioxin pollution under eutrophied conditions.

A key finding of this project is that long-term pollution of benthic habitats by toxic metals and dioxins does not significantly affect key nitrogen transformation processes (Broman et al., 2019; Broman et al., 2023). Denitrification in sediments removes excess fixed nitrogen, while dissimilatory nitrate reduction to ammonium (DNRA) converts nitrate to ammonium, retaining nitrogen within the aquatic system. Both denitrification and DNRA rates at a highly polluted (metals and dioxins) coastal area were found to be within the range of a national reference site and other unpolluted sites in the Baltic Sea (Broman et al., 2023). This result was supported in experimental studies with varying cadmium and oxygen concentrations, over a period of 21 days. Studies showed that bottom water oxygen, rather than cadmium pollution, largely regulated benthic denitrification and production of greenhouse gas dinitrogen oxide, and dinitrogen (Broman et al., 2019). These findings suggest that the key benthic ecosystem functions of denitrification and DNRA are more affected by eutrophication and organic carbon enrichment than by historic pollution of metals and dioxin in Baltic Sea sediment (Broman et al., 2023).

This project also showed that polluted sediment hosts nitrogen-cycling microbial communities genetically adapted to metal pollution (Broman et al., 2023). This was indicated by an overrepresentation of metal resistance genes in a study of the outer harbor of Oskarshamn in Sweden. Some resistance genes were matched to known denitrifying organisms, helping to explain why denitrification was little affected by toxic metal and dioxin pollution. These results of denitrification/DNRA rates and resistance genes suggest an important adaptation of nitrate-reducing bacteria to metals, resulting in a more metal-tolerant microbial community with persistent nitrate reduction in industrially polluted harbor sediment.

Consequently, the results suggest that microbial nitrogen cycling is more impacted by eutrophication, specifically the availability and quality of organic carbon and low oxygen conditions, than by metal and dioxin pollution. A collaborative study with researchers at

Stockholm University using experimental mesocosms showed a subtle effect of phytodetritus-derived organic matter quality on active benthic microeukaryotic communities (Albert et al., 2021). Given the indications of microbial community effects from organic matter quality, climate-related modifications in the future composition of settling organic matter from phytoplankton blooms to the aphotic sediments of the seafloor could alter microbenthic community composition and functioning (Albert et al., 2023). Further research will be necessary to better clarify which qualitative features of organic matter drive benthic community responses. The project also presented results from a forecast study using correlative niche modeling, that enhance our understanding of how future environmental changes predicted from climatic scenarios may influence the presence and geographical distribution of different denitrifying organisms across the Baltic Sea (Abdelgadir et al., 2023).

Taken together, the main outcomes of the project are important contributions to our understanding of the effects of pollution and eutrophication on the Baltic Sea benthic microbial ecosystem functioning.

2. The project's contribution to the international research frontline

This project contributed to significantly advance the international research frontier through new knowledge from participating in two key collaborative studies in the global-scale meta-analysis of environmental microbial communities: the Earth Microbiome Project (Thompson et al., 2017) and the Genomes from Earth's Microbiomes (GEM) project (Nayfach, et al., 2021). Coordinated protocols and innovative analytical methods facilitated the exploration of bacterial and archaeal diversity patterns on an unprecedented scale. These efforts resulted in a comprehensive reference database that provides global context to genomic data and a framework for integrating data from future studies, thereby enhancing our understanding of Earth's microbial diversity (Nayfach, et al., 2021; Thompson et al., 2017). The GEM project cooperation expanded our knowledge of the known global phylogenetic diversity of bacteria and archaea by 44% (Nayfach, et al., 2021). Findings underscore the influence of ecological niches on the global richness of environmental bacteria, and for example reveal the role of environmental conditions temperature, oxygen, salinity and association with other organisms for bacterial community richness and composition. Aquatic sediment bacterial communities, particularly those in coastal Baltic Sea benthic habitats, are among the most diverse, contributing new insights to the research field (Espinola et al., 2017; Nayfach, et al., 2021; Thompson et al., 2017). These international research frontline cooperations underscore the value of genome-centric approaches for revealing genomic properties (Nayfach, et al., 2021) of uncultivated microorganisms that affect ecosystem processes.

3. The contribution of the research to the knowledge of the Baltic Sea Region and Eastern Europe

The outcomes of this project provide improved understanding of how major environmental changes in the Baltic Sea ecosystem, such as oxygen depletion and pollution, impact the benthic ecosystem, its functioning, and stability. Specifically, the project offers important

information on how environmental toxic metals and dioxins pollution, and eutrophication, can influence key benthic nitrogen cycling, denitrification and dissimilatory nitrate reduction to ammonium. The project's results reveal the genetic adaptation of nitrate-reducing bacteria to metals at a long-term polluted harbour, resulting in a more metal-tolerant microbial community with persistent nitrate reduction. Since incomplete nitrate reduction results in the production of the greenhouse gas dinitrate oxide, and the process reverts carbon sequestration, these results are also of relevance for better understanding of the carbon sink capacity of polluted Baltic Sea coastal sediments. More broadly, these outcomes are relevant for understanding the ecological and environmental processes shaping benthic ecosystem functions in the Baltic Sea.

From a more applied perspective, and through collaboration with researchers in a project led by Gunnarsson at Stockholm University, analyses of the sediment microbial community at the industrially polluted harbor of Oskarshamn's municipality were conducted during large-scale tests for more environmentally sustainable remediation solutions, such as thin-layer bio-capping. Results of these studies contribute with valuable insights into new strategies for managing highly polluted areas in the Baltic Sea.

The outcomes of this project enable the integration of microbial ecological indicators with existing Baltic Sea benthos quality assessments. Outcomes directly relate to directives initiated by the European community, such as the Water Framework Directive and the Marine Strategy Framework Directive, which address the chemical status and quality of the marine environment. Alongside the Baltic Sea Action Plan, directives aim to achieve Good Environmental Status regarding qualitative descriptors, including biological diversity, eutrophication, and contaminants.

The results of this project strengthen and advance our ecological understanding of the effects of environmental changes in the Baltic Sea area. This knowledge enhances our understanding of ecologically relevant scenarios regarding the capacity of microbial benthic systems to respond to environmental changes. It is particularly relevant as climate change is accelerating at higher latitudes and predicted to significantly affect the Baltic Sea ecosystem. By providing insights into the microbial processes and adaptations of micro-benthic communities, this research contributes to knowledge for the development of effective strategies for mitigating the impacts of environmental stressors and promoting the environmental sustainability of the Baltic Sea Region.

4. New research questions that the project has led to

The Baltic Sea Region and other higher latitude areas are experiencing more rapid climate change compared to lower latitude regions. Predictions indicate that future climate change will continue to accelerate in the region. This project has raised several new research questions, including: What environmental changes will the Baltic Sea benthic ecosystem face, and how will benthic communities respond? In this context, a particularly important question is: What roles do micro-benthic community diversity and functioning have in the sequestration of Baltic Sea carbon across space and time? Microbial community metabolisms are crucial for nitrogen and carbon transformation, determining how organic

carbon is sequestered and becomes a so-called carbon sink at the sea bottom, and how much carbon or nitrogen is produced as greenhouse gases. It is important to better understand which qualitative features of organic matter drive benthic micro-community responses. This project has generated several further research questions, some of which are the focus of new research project plans and could provide research guidance for more sustainable management of changing Baltic Sea environments.

5. Dissemination of the results of the project within and outside the research community

Publications- peer review scientific international journals

Abdelgadir M, Broman E, Dinnétz P, Olofsson M, Sjöling S. Future increase of filamentous cyanobacteria in coastal Baltic Sea predicted by multiple realm models of marine, terrestrial, and climate change scenarios. (under review, SSRN: dx.doi.org/10.2139/ssrn.4727236)

Abdelgadir M, Raymond C, Sjöling S, and Dinnétz P. Benthic denitrification capacity association with changes in habitat configuration in a small-scale system. (under review, SSRN: dx.doi.org/10.2139/ssrn.4727523)

Broman E, Abdelgadir M, Stefano Bonaglia S, Forsberg SC, Wikström J, Gunnarsson JS, Nascimento FJA, Sjöling S. 2023. Long-Term Pollution Does Not Inhibit Denitrification and DNRA by Adapted Benthic Microbial Communities. Microbial Ecology, 86, 2357–2372. doi.org/10.1007/s00248-023-02241-7

Abdelgadir M, Alharbi R, AlRashidi M, Alatawi S.A., Sjöling S, Dinnétz P. 2023. Distribution of denitrifiers predicted by correlative niche modeling of changing environmental conditions and future climatic scenarios across the Baltic Sea. Ecological Informatics, 78, 102346. doi.org/10.1016/j.ecoinf.2023.102346

Albert S, Hedberg P, Motwani NH, Sjöling S, Winder M, Nascimento FJA. 2021.Phytoplankton settling quality has a subtle but significant effect on sediment microeukaryotic and bacterial communities. Scientific Reports 11, 24033. doi.org/10.1038/s41598-021-03303-x

Nayfach S, Roux S, Seshadri R. et al. 2021. A genomic catalog of Earth's microbiomes. Nature Biotechnology 39: 499–509. doi.org/10.1038/s41587-020-0718-6

Broman E, Motwani NH, Bonaglia S, Landberg T, Nascimento FJA, Sjöling S, 2019. Denitrification responses to increasing cadmium exposure in Baltic Sea sediments. Aquatic Toxicology 217: 105328. doi.org/10.1016/j.aquatox.2019.105328

Thompson LR, Sanders JG, Daniel McDonald, et. al., 2017. A communal catalogue reveals Earth's multiscale microbial diversity. Nature 551, 457–463. doi:10.1038/nature24621

Textbook

Sjöling S, van Elsas JD, Andreote F, Mazza Rodrigues JL. 2019. Chapter on Soil Metagenomics-deciphering the soil microbial gene pool, chapter 14, in Modern Soil Microbiology, Third ed (Ed JD van Elsas, JT Trevors, As Rosado, P Nannipieri) CRC Press, pp 227-243. ISBN 042960792X, 9780429607929

Completed manuscripts

Abdelgadir M, Broman E, Bonaglia S, Dinnétz P, Nascimento F JA, and Sjöling S. Association between sediment denitrification rates and transcript abundances of denitrification genes. Completed Manuscript.

Garrison JA, Wikström J, Bonaglia S, Broman E, Gunnarsson JS, Francisco JA N, Sjöling S. Effect of thin layer capping treatments on microbial and meiofaunal community diversity. Manuscript to be submitted.

Debates, popular science dissemination

Sjöling S. Engelsbergssymposiet: Invited Key speaker, TV-recorded symposium and panel debate. Sjöling presented research from this project on "Hidden Biodiversity in the Service of a Sustainable Society" at the Engelbergs Bruk symposium titled "Where is Life Science Heading in the Future" and participated in a panel debate in June 2018. The international symposium, organized by the Stockholm Science City Foundation and the Axel and Margaret Ax:son Johnson Foundation, gathers representatives from various organizations and fields to discuss the present and future development of life sciences. Topics include global political standpoints, challenges, and opportunities for countries aiming to lead in life sciences, with a particular focus on Sweden's future role.

Interview of Sjöling in the journal Kemivärlden: Biotech med Kemisk Tidsskrift, nr 8, 2017 by Boel Jönsson on research and the contribution to the international Earth Microbiome Project.

Project members participated at European Researchers' Night (ForskarFredag), September.

Thesis, Ph. D. Environmental Science

Abdelgadir M. 2024. Aquatic ecosystem function and environmental change across spatial scales. Environmental Science & BEEGS, Södertörn University, SDD 231. ISSN 1652-7399. All but salary and small expenses funded by this project 77/17.

Other dissemination within the research community

Sjöling S. The Earth Microbiome Project, Aquatic ecosystem perspectives. Biodiversity Workshop, Södertörn University, organized by Sanyal A, CBEES funded, June 10-11, 2024. Speaker.

Sjöling S. Ecosystem functions & processes. Environmental Science Seminar, Södertörn University, January 13, 2022.

Abdelgadir M, Dinnétz P, Sjöling S. Marine research Day, Swedish Society for Marine Sciences 'Svenska havsforskningsföreningen'. December 16, 2020. *poster presentation.*

Abdelgadir M, Dinnétz P, Sjöling S. EcoChange Conference, Umeå University, November 10-23, 2020. *Abdelgadir oral poster presentation.*

Dionisi H, Espinola F, Lozada M, Mc Cormack W, Sjöling S. Characteristics of Baltic Sea coastal sediment microbial ecosystem functions and community structure in a global perspective. Baltic Sea Science Congress, Stockholm, Sweden, August 19-23, 2019.

Sjöling, S. Department of Earth and Environmental Sciences, University of Milano-Bicocca, Milano, Italy, June 17, 2019. *Guest lecturer.*

Albert S, Hedberg P, Motwani NH, Sjöling S, Winder M, Nascimento FJA. Structural and functional response of microbenthic communities under different organic matter settling scenarios. Baltic Sea Science Congress Stockholm, Sweden, August 19-23, 2019. *poster.*

Abdelgadir M. Baltic Sea Science Congress, Stockholm, August 13-19, 2019.

Sommer C, Hu YOO, Gunnarsson J, Dinntez P, Sjöling S. Major Baltic Sea Inflow event and Baltic Sea sediment microbial bacterial community structure in response to environmental change from a Major Baltic Inflow event. Marine Science Conference, Göteborg, Sweden, November 1, 2017. *poster presentation.*

Five most important conferences

Abdelgadir M, Dinnétz P, Sjöling S. Benthic denitrification capacity association with changes in habitat configuration in a small-scale system. Ecology Across the Borders, Organized by British Ecological Society, UK, December 9-15, 2021. *poster presentation.*

Sjöling S. Member of the International Scientific Committee at the 3rd Open Conference of Functional Metagenomics International 2019, Trondheim, Norway, June 16–19, 2019.

Sjöling S, Sommer C, Dinnétz P, Dionisi H, Espinola F, LOzada M, Broman E, Motwani N, Nascimento F, Bonaglia S. Soft bottoms- Ecosystem function and metapopulation patterns of benthic communities exposed to pollution. 3rd Open Conference of Functional Metagenomics International, Functional Metagenomics ,Trondheim, Norway, June 16-19, 2019. *Invited speaker.*

Sommer C, Hu Y, Nascimento F, Gunnarsson J, Dinnétz P, Sjöling S. Changes in sediment bacterial community composition and diversity patterns following a major inflow event into the Baltic Sea. Sommer oral presentation. Baltic Sea Science Congress, Stockholm, Sweden, August 19-23, 2019. *Sommer oral presentation.*

Sjöling S. Sub-polar sediment comparative metagenomics and applied ecosystem functions. Procagenomics, 7th European Conference on Prokaryotic and fungal genomics, Göttingen, Germany, September 19-22, 2017. *Invited plenary lecture.*