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VULNERABILITY OF THE BALTIC SEA
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Physical, chemical and biological features, which increase or may increase the vulnerability of the brackish Baltic Sea ecosystem to anthropogenic chemicals compared to marine or freshwater environments

Presently the Baltic Sea receives a high load of a variety of chemicals, and there is a continuous input of known and unknown substances from the large catchment area. The relatively small water volume offer a small degree of dilution, that is a given contaminant load will result in higher concentration in the Baltic Sea compared to anthropogenic input to other more distinctive marine areas with better water turnover rates. Since the water exchange is slow, the harmful substances will also remain in the Baltic for a longer period of time. Low temperature and permanent stratification reduces the chances for volatilization and degradation. As the Baltic Sea is shallow, sediment resuspension is relatively high, which hampers the circulation of chemicals.

The short geological history of the Baltic Sea along with its brackish nature which puts strains on both marine freshwater organisms, has resulted in low species diversity. The composition of species, however, is unique, where organisms of both marine and freshwater origin live side by side. There are both some arctic relicts and a number of endemic species. Low biodiversity corresponds to a reduced ecosystem resilience, i.e., if a ecologically important species would decline there are no alternative species that can uphold their functions in the ecosystem. Another aspect of biological sensitivity is that most species live close to their physiological tolerance limits regarding the ambient salinity. This has been shown to correspond to reduced tolerance at the individual level to additional stress, e.g. contaminants.

A cause of concern is that most investigated Baltic populations have a relatively low genetic variability. Reduced genetic variation hampers adaptation to new selective regimes, e.g. toxic contamination or changed climate, and affects thereby overall ecosystem resilience. There are also genetically deviant populations in the Baltic Sea. This implies that in case of dramatic declines in population size, important traits for surviving in this harsh environment can be lost

The present situation with high concentrations of a number of contaminants increases the risk for harmful effects if additional substances/amounts are released. From a risk perspective it is also important to highlight the fact that there are huge knowledge gaps regarding how chemicals in complex mixtures behave and transform. Another area where far too little is known is the biological effects of different exposures.

Altogether, it is clear that there are physical, chemical and biological aspects and features of the Baltic Sea that call for more restrictive handling of chemicals. Preliminary calculations of a quantitative estimate of the higher sensitivity of the Baltic Sea compared to NE Atlantic has been performed based on studies on physiological responses at the individual level in several species. However, if a quantitative estimate is needed to establish a risk factor this has to be further studied and elucidated. Aspects of climate change and invasive species, and their bearing on contaminants, are not included in the matrix, since it would be solely based on speculations. Aspects that are to be considered in the first place when discussing the sensitivity of the Baltic Sea to contaminants are listed below. It should be observed that some of the characteristics included in the list (e.g. semi-enclosed sea, large catchment area) and their implications for hazardous substances are well-established facts, whereas the implications of some other features are less clearcut.

Feature	Consequence	Implication for exposure or effects of chemicals
Physical features		
Semi-enclosed sea	Slow exchange of water Minimal tides, low sediment circulation	Trapping of chemicals Stocking up of chemicals in anoxic, deep sediments, occurrence of stable hot spot areas (sedimentation areas)
Large, densely populated catchment area	High inflow of freshwater that contain contaminants High atmospheric deposition of anthropogenic contaminants	High input of hazardous substances The present situation with high concentrations of contaminants increases the risk if additional substances are introduced, especially given the lack of knowledge about risks from 'cocktails' of contaminants
Shallow compared to the Atlantic Sea	Small water volume compared to seas and hence smaller dilution of hazardous substances compared to seas Shallow results in more wind driven sediment resuspension, which keeps chemicals in circulation longer, lengthening their elimination half life	Higher concentrations of chemicals
Low temperature	Slower hydrolysis and biodegradation of organic compounds	Higher concentrations of slowly degradable chemicals Low recovery of disturbed communities (low growth rates)
Ice and snow cover (Furman et al. 1998)	Inhibition of photodegradation and volatilization	Higher concentrations of photodegradable and volatile chemicals
Short day conditions in autumn and winter	Inhibition of photodegradation	Higher concentrations of photodegradable chemicals

Permanent stratification of water because of halocline Temporary stratification of water because of thermocline (Furman et al. 1998)	Inhibition of exchange of water and dissolved substances as well as particulate matter across halocline or thermocline When chemicals are trapped in deep water, important elimination pathways are blocked, i.e. volatilization and photodegradation	Affects partitioning and thus concentrations of chemicals
Minimal tidal sea level fluctuations	Slow ventilation of chemicals in the coastal zone	Higher concentration of chemicals in the coastal zone
High sedimentation rates compared to oceans (Harri Kankaanpää, FIMR) (This should be considered together with increased sediment resuspension in shallow areas, see above)	Efficient input of particle-bound contaminants to sediments	Increased sedimentation reduces the bioavailability of pollutants and increases biodilution. However, if contaminants adsorb to palatable substances, this might increase bioavailability and bioaccumulation. The sediment may function as a source of hazardous substances, when the input to the sea stops. Due to equilibrium partitioning substances will be released to the water from the sediment, once the concentration in the water sinks low enough
Hydrodynamic fronts e.g. in the eastern Gulf of Finland	Selective sedimentation of metals (Harri Kankaanpää, FIMR)	Affects the proportions of chemicals present in the different compartments

Chemical features

Brackish water, salinity range from 0 to 20 ppt	Salinity affects speciation of metals	Toxicity of some metals is inversely related to salinity (metals appear in more toxic forms in the low saline water compared to seawater) (e.g. Reviewed by Kautsky and Andersson 1997)
Low calcium concentration compared to oceans (Grasshoff and Voipio 1981)	Increased permeability of cell membranes Higher affinity of organisms to toxic 2+ ions (metals)	Increased uptake of metals compared to the seawater

Anoxic and hypoxic sediments		Hazardous substances, such as metals, PCB and PAH, are often immobilized in sediments under hypoxic or anoxic conditions. An improved oxygen situation may increase the mobilization of chemicals from sediments through an increase in bioturbationA (Jonsson 1992, Sternbeck et al. 1999) Suboxic conditions favour creation of organic mercury with much higher toxicity

Biological features

Short history of the Baltic Sea (the current salinity has existed about 3000 years)	Low biodiversity since few organisms have adapted to live in the Baltic Sea. The food webs are simple compared to oceans	Simple food webs are more vulnerable to environmental changes Low resistance to local extinctions Low biodiversity corresponds to reduced ecosystem resilience, i.e. if species that have an important ecological role in the ecosystem would decline there are no alternative species that can uphold their functions in the ecosystem. Bladder wrack (*Fucus vesiculosus*) and blue mussel (*Mytilus edulis*) can be regarded as key species in the Baltic coastal zone. (e.g. Kautsky and Andersson 1997) Low resistance to invasion by alien species
Most species living in the Baltic Sea are originally marine or freshwater species and thus live close to their physiological tolerance limits regarding the ambient salinity	A higher metabolic demand to cope with the osmotic stress may partly explain why individuals in the Baltic Sea are often much smaller than individuals of the same species in freshwater or the Atlantic	Reduced tolerance at the individual level to additional stress, e.g. contaminants This makes species living in the Baltic Sea more vulnerable to chemicals compared to marine or freshwater species (Tedengren and Kautsky 1987; Tedengren et al. 1988, Eklund 2005)

Species inhabiting the Baltic Sea can largely be described as 'generalists' rather than 'specialists'. However, this can largely be explained by the low inter-specific competition, i.e. they *can* be generalists in the Baltic. Gammarids, for example, are generalists on the Swedish east coast but specialists on the west coast	Generalists have a broader ecological niche, whereby they are able to withstand harsher and more variable conditions than more specialized species	Higher tolerance to e.g. contaminants compared to species inhabiting less extreme ecosystems (however, the consequence of loosing one species in this species-poor ecosystem can not be overlooked)
A majority of investigated Baltic populations (29 species) have lower genetic variability than populations of the same species from the Atlantic (Johannesson and André 2006) Important Baltic plant species, such as macroalgae and seagrass, can have a low degree of sexual reproduction, i.e. whole populations can be constituted by clones		Reduced genetic variation hampers adaptation to new selective regimes, e.g. toxic contamination or changed climate Further, if the Baltic Sea is dominated by genetically depauperate populations, this has implications for ecosystem resilience
Some of the investigated populations living in the Baltic Sea show clear evidence of being genetically deviant from populations in the Atlantic (Väinölä and Hvilsom 1991, Nilsson et al. 2001, Luttikhuizen et al. 2003, Johannesson and André 2006)		In case of dramatic declines in population size, important traits for surviving in this harsh environment can be lost
The Baltic Sea contains unique lineages for some species, as well as a newly discovered endemic species (Pereyra et al. 2009)		Special concern should be attributed a marginal ecosystem that produce and protect more or less extreme evolutionary lineages
Cyanobacterial blooms produce liver toxins		Peak concentrations of natural toxins (possibly enhanced by anthropogenic nutrient input) may interfere with toxokinetics of man made hazardous substances. Whether this is antagonistic or synergistic interference is not yet known (Harri Kankaanpää, FIMR)

This matrix is a modified version of an annex in a HELCOM working document (prepared by Finland). Modifications and additions have been made by T. Elfwing, in large on the basis of comments from R. Elmgren, M. McLachlan, L. Kautsky, M. Gilek, M. Tedengren, C. Bradshaw, B. Sundelin, B.-E. Bengtsson, B. Eklund and Å. Larsson.

References

Bergström, L., Bruno, E., Eklund, B. and Kautsky, L. 2003. Reproductive strategies of *Ceramium tenuicorne* near its inner limit in the brackish Baltic Sea. Botanica Marina 46:125-131.

Braunschweiler, H. and Koivisto, S. 2000. Fate and effects of chemicals in the Nordic environment related to the use of biocides. TemaNord 2000:559, Nordic Council of Ministers, Copenhagen. 135 pages. ISBN:92-893-0471-5

Eklund, B. 2005. Development of growth inhibition test with the marine and brackish water red alga *Ceramium tenuicorne*. Marine Pollution Bulletin 50: 921-930

Furman, E., Dahlström, H. and Hamari, R. 1998. The Baltic - Man and Nature. Otava Publishing Company Ltd., Helsinki. 160 Pages. ISBN 951-15047-2

Grasshoff, K. and Voipio, A. 1981. Chemical oceanography. In: The Baltic Sea, edited by A. Voipio. Elsevier, Amsterdam

HELCOM 1998. The third Baltic Sea pollution load compilation. Baltic Sea Environment Proceedings No. 70. Helsinki.

Jansson, B-O. and Dahlberg, K. 1999. The environmental status of the Baltic Sea in the 1940s, today, and in the future. Ambio 28:312–319.

Johannesson, K. and André, C. 2006. Life on the margin: genetic isolation and diversity loss in a peripheral marine ecosystem, the Baltic sea. Molecular Ecology 15: 2013-2029.

Jonsson, P. 1992. Large scale changes in Baltic Sea sediments during the twentieth century. PhD Dissertation, Uppsala University.

Kautsky, N. and Andersson, S. 1997. The Baltic Sea environment, and its sensitivity to pollutants with emphasis on organic tin compounds. PM KemI 3/97.

Lilja, K., Prevodnik, A., Gardeström, J., Elfwing, T., Tedengren, M. and Bollner, T. 2008. Regional differences in mRNA responses in blue mussels within the Baltic proper. Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology 148: 101-106.

Pereyra, R.T., Bergström, L., Kautsky, L. and Johannesson, K. 2009. Rapid speciation in a newly opened postglacial marine environment, the Baltic Sea. BMC Evolutionary Biology 9:70.

Prevodnik, A., Gardeström, J., Lilja, K., Elfwing, T., McDonagh, B., Petrović, N. Tedengren, M., Sheehan, D., Bollner, T. 2007. Oxidative stress in response to xenobiotics in the blue mussel *Mytilus edulis* L.: Evidence for variation along a natural salinity gradient of the Baltic Sea. Aquatic Toxicology 82: 63-71.

Reusch T. B. H., Stam, W. T. and Olsen, J. L. 2000. A microsatellite-based estimation of clonal diversity and population subdivision in Zostera marina, a marine flowering plant. Molecular Ecology 9:127-140.

Reusch, T. B. H., Ehlers, A., Hämmerli, A. and Worm, B. 2005. Ecosystem recovery after climatic extremes enhanced by genotypic diversity. Proceedings of the National Academy of Sciences 102:2826-2831

Sternbeck, J., Skei, J., Verta, M. and Östlund, P. 1999. Mobilisation of sedimentary trace metals following improved oxygen conditions. TemaNord 1999:594.

Tedengren, M., Arnér, M. and Kautsky, N. 1988. Ecophysiology and stress response of marine and brackish water *Gammarus* species (*Crustacea, Amphipoda*) to changes in salinity and exposure to cadmium and diesel-oil. Marine Ecology Progress Series 47: 107-116.

Tedengren, M. and N. Kautsky. 1987. Comparative stress response of to diesel oil and salinity changes of the blue mussel, *Mytilus edulis*. Opehlia 28: 1-9.

Ytreberg, E., Karlsson, J., Hoppe, S., Eklund, B. and Ndungu, K. Effects of organic complexation on copper accumulation and toxicity to the estuarine red macroalga *Ceramium tenuicorne.* A test of the free ion activity model (Submitted to Envrionmental Science and Technology)

Ytreberg, E., Karlsson, J., Ndungu, K., Hassellöv, M., Breitbarth, E. and Eklund, B. Influence of salinity and organic matter on the toxicity of Cu to a brackish water and marine clone of the red macroalga *Ceramium tenuicorne* (to be submitted to Ecotoxicology and Environmental Safety)