# Hypoxia in the Baltic Sea:

## *Recommendations to BalticSea2020 and Naturvårdsverket*

*Executive Summary*

**Background**

A project on *Understanding Hypoxia in the Baltic Sea* was initiated in January 2007 under the direction of Prof. Daniel Conley, Marie Curie Chair, GeoBiosphere Science Centre, Lund University, with funding provided by *BalticSea2020*. The goal was to create an improved understanding of hypoxia in the Baltic Sea and determine if there are technical solutions to mitigating the devastating environmental effects of hypoxia on living resources and if is possible to restore the self-purifying biogeochemical processes. Hypoxia is usually defined as oxygen concentrations less than 2 mg/L where large-scale biological and biogeochemical effects occur.

Three workshops were held with participation from scientists around the Baltic Sea together with involvement of internationally recognized scientists. In total 60 different scientists from 10 different countries participated in these workshops. The workshops were:

1. Understanding Hypoxia in the Baltic Sea,17-19 April 2007, GeoBiosphere Science Centre, Lund University.
2. Coastal Hypoxia in the Baltic Sea, 16-18 October 2007, Åbo Akademi University.
3. Potential management techniques, environmental effects and ethics, 27-29 November 2007, GeoBiosphere Science Centre, Lund University.

A final meeting "Possible Solutions to Oxygen Problems in the Baltic Sea" was held at the Royal Swedish Academy of Sciences, Stockholm on 24 January 2008 with co-funding from the Swedish Environmental Protection Agency (Naturvårdsverket). The talks presented are available on the *BalticSea2020* web site http://www.balticsea2020.se/.

Hypoxia is a globally significant problem with over 375 reported sites suffering from hypoxia due to excess nutrient loading from anthropogenic sources. The International Panel for Climate Change (IPCC) also recognizes that hypoxia is a problem of growing concern with projected global changes. The synthesis activities as part of the "Hypoxia Project" have shown that climate and anthropogenic pressures both have played a role as drivers of hypoxia through time in the Baltic Sea. Superimposed on this natural variability, hypoxia has become considerably more widespread and prevalent in modern historical times, c. 1950-present, in both the coastal zone and the open waters of the Baltic Sea. The lack of oxygen reduces the available habitat for living resources, changes the self-cleansing biogeochemical processes so that P release from the bottom is enhanced and the processes of denitrification reduced, creating a vicious circle that helps to sustain eutrophication.

After the first workshop, 3 projects were initiated with funding from *BalticSea2020* to assist in the workshop's goal of making recommendations based upon sound scientific advice. These projects included: "Simulations of Some Engineering Methods Proposed to Improve Oxygen Conditions in the Baltic Proper" (Bo Gustafsson, Göteborg University), "What Controls Sediment Phosphorus Burial in the Baltic Sea?" (Caroline Slomp, Utrecht University, The Netherlands), "Benthic-pelagic Coupling in the Baltic Sea: The Effects of Redox Changes on Sediment P Release and Implications for Water Quality" (Slomp and Gustafsson).

**Results**

*Model experiments.* Model experiments were carried out using the BALTSEM (Göteborg University and the Baltic Nest Institute) and RCO-SCOBI (SMHI) models to consider generalized engineering solutions that reduce hypoxia. Further documentation on the results from this project can be found at the *BalticSea2020* website. Since it was not possible to test all proposed engineering solutions, they were grouped into four general categories:
1. *Deep water oxygenation.* Various strategies have been suggested to add oxygen directly into deep-water, for example bubbling. The amount of oxygen need to keep the Baltic Sea above 2.8 mg/l, the threshold for mild hypoxia, was calculated. The amount of oxygen varied between 2-6 million tons of oxygen needed annually to keep the bottom waters from becoming hypoxic.
2. *Increased exchange across the Drogden Sill.* This experiment simulated enhanced salt water input into the Baltic Sea, for example the O2Gruppen Saltlock. Based on our current understanding of the Baltic Sea and from the model results, enhanced salt water input into bottom waters can be expected to increase stratification and the area of hypoxia.
3. *Closing the Drogden Sill.* A suggestion was made to reduce saltwater inflow, freshening the Baltic. Model results demonstrated that there is a long transitional stagnation period following reduced saltwater inflow during which hypoxia increases in deeper waters. There are improvements in water quality in the long run (>30 years) at the cost of a drastic reduction of salinity.
4. *Halocline ventilation by mid-water mixing (50 m to 125 m).* The models, in quite close agreement, show that halocline ventilation gives improved oxygen concentrations and no change in surface salinity. There is a decrease in deep water salinity, but within the range of natural variability. This physical mitigation appears to be the most feasible, but the effects on biogeochemical processes remain untested.

The models give consistent and plausible responses, although quantitative differences in sensitivity were obtained from the different models. The models need to improve, in particular, the parameterizations of sediment processes. Further, there is a need to link the deep-water models to models dealing with hypoxia in the coastal zone as well climate change. The processes and forcing functions for the formation and maintenance of hypoxia in shallower coastal waters differ and should be dealt with in separate models.

*Chemical P sequestration.* In freshwaters and sewage treatment plants aluminum and a variety of other chemicals have been used to chemically bind and precipitate phosphorus. One goal to alleviate hypoxia in the deeper basins of the Baltic Sea is enhance the permanent burial of P in Baltic Sea sediments. A recent Naturvårdsverket report by "Blomqvist and Rydin (2008) P-uppbindning i Östersjöns bottensediment" addresses many of the issues concerning P sequestration. While we can use the successful experience gained in small lakes, there are significant gaps in our present knowledge with regard to P precipitation in seawater. Potential problems include reductions in the binding capacity in seawater, toxicity for benthic organisms and the potential for co-sequestration of dissolved silicate.

*Biomanipulation.* Biomanipulation is the practice of altering biological communities through manipulating biological interactions. The classic report for fresh waters by Lars-Anders Hansson (1998) "Biomanipulering som restaureringsverktyg för näringsrika sjöar. NV Rapport 4851." is currently being updated to include possible remediation in the Baltic Sea. Although some success has been achieved in freshwaters, the enormous size of the Baltic Sea adds to the uncertainty of the effectiveness on biomanipulation on such a massive scale. It might be possible to implement different types of biomanipulation (predator addition, reduction in fishing, artificial mussel beds, algal harvesting) on the local scale in coastal waters, especially in "hot spots." Experience from fresh waters is that major achievements can only be made if the nutrient supply is reduced.

*Re-establish the functioning of the coastal filter.* Previous research has established the importance of the coastal zone and its ability to act as an important biofilter utilizing and processing nutrients before they make it out to open waters of the Baltic Sea, although the removal of nutrients remains unquantified. With coastal eutrophication, large areas of the coastal zone have been degraded with hypoxia common in the archipelago regions. However, we have a limited understanding of the spatial and temporal extent of hypoxia in the coastal zone and the impact of the loss of the coastal filter on the Baltic Sea.

**Conclusions and Recommendations**

We must reduce nutrients for any mitigation measure to be effective. We should redouble our efforts to make nutrient reductions in the Baltic Sea and go beyond the first stages of the Action Plan to specific measures within each country to reduce nutrient loads. Engineering solutions may enhance or accelerate the recovery process provided that nutrient inputs are reduced.

Any engineering solution that changes the overall salinity of the Baltic Sea should be avoided, since that would lead to significant alterations of species composition, in pelagic and benthic ecosystems. Changes in salinity are probably illegal with regard to the EU Habitats Directive and are likely politically unacceptable to many of the countries surrounding the Baltic Sea.

Engineering projects to add oxygen to the bottom waters of the Baltic Sea will need to consider the enormous amount of oxygen required (2-6 million tons annually) to keep the Baltic Sea from going hypoxic.

Model experiments demonstrate that halocline ventilation is the only engineering solution tested that cannot be ruled out.

There is no known P sequestration method that is mature enough for immediate implementation in the Baltic Sea. All techniques require preliminary experiments in the laboratory and at the mesocosm scale to show that the P losses are permanent and stable under varying redox conditions. This approach could provide a way to start reducing P pools in coastal regions. As a cautionary note, addition of any chemical will violate the principle of reversibility, e.g. once added to the Baltic Sea a chemical cannot be removed, no matter if the response obtained is desirable or not. Addition of chemicals may violate the London Convention.

Significant gaps remain in understanding the P and N biogeochemical cycles in the Baltic Sea. Basic questions such as “What are the sizes and location of the mobile/bioavailable P fraction and permanent P sinks in Baltic Sea sediments?” needs to be answered. In addition, experience from fresh waters shows that increased Fe-P burial through artificial oxygenation may not be sufficient to significantly increase P burial. With regard to N, disagreement exists on the impact of oxygenation on denitrification with predictions showing both positive and negative effects.

Biomanipulation may be a measure implemented locally in “hot spots” and in the coastal zone. The effectiveness of implementation on the scale of the Baltic Sea should be carefully considered and a thorough risk analysis of possible alternative interactions, such as disruptions in the food-web, undertaken.

Because of the increases in eutrophication and hypoxia in the coastal zone and the ability of the coastal filter to help process and remove nutrients, e.g. bury P and remove N with denitrification, we need to restore the degraded abilities of the coastal filter.

**Specific Recommendations Regarding Naturvårdsverket "Letter of Interest" and For Future Funding by Foundations**

The current announcement for a "Letter of Intent" should be broadened to include innovative measures that can reduce nutrient supply rapidly from land-based sources. Enhancing the reduction of nutrient loading to the Baltic Sea should be the highest priority.

The current announcement focusing only on the effects of phosphorus leakage from sediments should be broadened to include evaluation of the effects of mitigation on denitrification and living resources.

A "Call for a Letter of Interest" should follow a 3-step process. The first screening step is necessary to determine what proposals are of interest for further consideration of mitigations. A second step where a number of proposals are funded to set a tenable goal, finalize the design, make cost estimations, put together an Environmental Impact Assessment including potential effects on biota and impact on N & P biogeochemical nutrient cycles, including a risk analysis of unintended consequences, consideration of energy needs, and address legal issues. Only those engineering technologies that are considered feasible and mature enough should go forward to the pilot project stage in a 3rd stage of funding with adequate resources allocated for monitoring before, during and after implementation.

A study should be undertaken by Naturvårdsverket to determine the legal and ethical issues that will be encountered when implementing engineering solutions in the Baltic Sea.

The HELCOM Action Plan has been an important step forward for determining country allocations. However, a sector analysis covering both the costs and effectiveness of nutrient reductions needs to be carried out on a Baltic Sea basis as soon as possible to ensure implementation of adequate nutrient reductions. Helping this process along could be something addressed with new funding.

Experience from lakes tells us that simply adding oxygen to the Baltic Sea may in fact not help significantly in mitigating eutrophication. Studies, both models and experiments, are needed to test the effects of adding oxygen to the Baltic Sea on P and N biogeochemistry.

Studies are needed to examine techniques for enhancing P burial in Baltic Sea sediments. While it is unsure if these technologies will be used at the scale of the Baltic Sea because of legal and ethical issues, we can learn more about potential mitigation and its effects from these studies.

An evaluation of the current extent of hypoxia around the Baltic Sea in the coastal zone is needed. In addition, an evaluation of the ability of the coastal zone to process nutrients and remove them through burial and denitrification is also sorely needed.

Expert evaluation panels and synthesis activities involving a diverse group of highly qualified scientists should be instituted to evaluate various mitigation options and the functioning of the Baltic Sea ecosystem.

Respectively submitted,

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