Final Summary Report

Understanding the importance of the coastal zone for restoration efforts in the Baltic Sea

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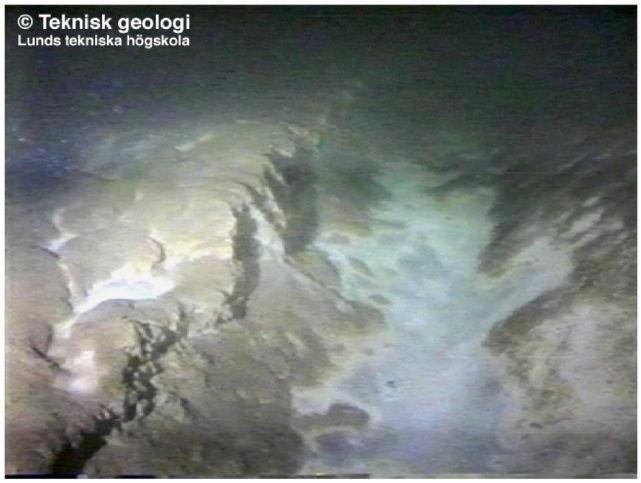

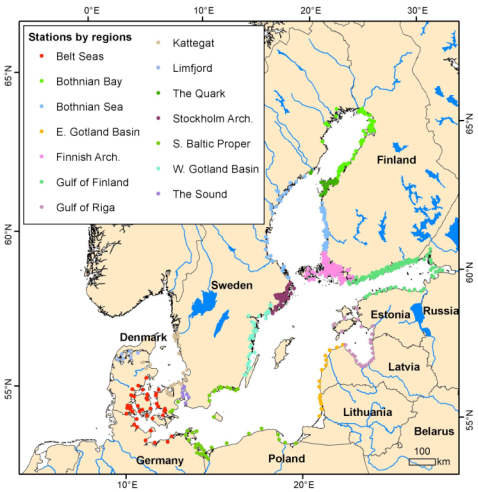

Final Summary Report

The following will summarize our activities regarding "Understanding the importance of the coastal zone for restoration efforts in the Baltic Sea" funded by Baltic Sea 2020 from 1 August 2008 – 31 December 2009 (extension to 30 June 2010). We will discuss our progress towards meeting our initial objectives, some of the success of our research and the reasons why we did not meet all of our initial objectives in the original plan.

Our efforts in this project were focused on evaluating conditions in the coastal zone of the Baltic Sea. It was believed that an unknown, but presumably large area of sediments, especially in the Stockholm and Finnish archipelagos, were devoid of macroscopic life due to the lack of oxygen, e.g. hypoxia. Surprisingly, there had been no previous systematic effort(s) to investigate the occurrence of hypoxia in the coastal zone, although some previous studies have been made on individual estuaries or by countries (e.g. Denmark).

Synthesis workshops

Our first coastal zone workshop in Åbo, Finland in October 2007 was part of our earlier funding from Baltic Sea 2020 and highlighted different case studies where hypoxia had been previously observed in the Baltic Sea. We discovered at that meeting that there were data available that had been collected in different monitoring programs, but never collated and analyzed collectively. Several of the participating individuals and organizations expressed interest to deliver their data for a more through analysis of coastal hypoxia if/when such an analysis was to be made.

Hence, our first effort with our current funding (2008-2010) was to hold a workshop to determine the availability of coastal data that were known. We invited a number of different data holders and scientists to Lund in November 2008. At that point we recognized that there was much more data available from the different countries than previously recognized. We set up a system to import the data into the databases at the Baltic Next Institute, Stockholm University. Our goal was to put together a community wide web-accessible database. We were enthusiastic after this workshop at the potential to create a database, however we never imagined the success of our efforts, which in turn proved to be much more laborious than anticipated.

Our efforts quickly bogged down due to the reluctance of many of the authorities to release the data for public access. In conjunction with the Baltic Next Institute, we have secured the long-term accessibility of the data, but that took time as separate negotiations were necessary with all the regional and national agencies that had collected data. What we didn't foresee was the tremendous amount of data we were able to obtain in the end. In all we obtained around 2 million records of data covering the entire Baltic coastal region! In addition, we quickly surpassed our own abilities to deal with such large data sets and were required to partner with someone who had capabilities of database handling and data analysis beyond our collective capabilities. Fortunately we were able to partner with Prof. Jacob Carstensen at the Baltic Nest Institute, National Environmental Research Institute, Aarhus University, Denmark, who was able to use his funding from the EU BONUS Project HYPER to help fund his activities in our Baltic Sea 2020 project. A second, smaller workshop was held in April 2010 to specifically discuss the data analysis and presentation of the data in a comprehensive way.

From late 2009 to present we are continuing to analyze the data. Given the number of disparate records and the large number of different sampling locations it is an on-going task. More time and effort is required to make this database into a useable community-wide web-accessible data

base, but more on that theme later in this report. During the process of compiling the data, we have presented our findings at national and international seminars and conferences (e.g. EUTRO 2010 in Nyborg, Denmark in June, and the Nordic Marine Science Conference in Strömstad, Sweden in September), and thus been able to incorporate additional information and viewpoints to our emerging holistic view of the problem, encompassing data from all countries bordering the Baltic Sea, and covering some 50 years (see below).

Occurrence and extent of hypoxia

The results of our data analysis are simply speaking spectacular. The Baltic Sea coastal zone contains examples of ecosystems that experience both episodic periods of hypoxia and systems with near permanent hypoxia. We found a widespread unprecedented occurrence of hypoxia across the coastal zone. We identified ca. 96 sites that have experienced hypoxia during the period 1955-2009 increasing the global total of sites that have reported hypoxia to around 500 sites, with the Baltic coastal zone containing nearly 20% of all known sites, world-wide wide (the global picture is based on estimates published in *Science* and other top-ranked international journals). Most sites experienced episodic hypoxia, which is a precursor to the development of seasonal hypoxia. Most importantly, we found that the number of monitored areas with hypoxia has steadily increased with time, suggesting that the problem with hypoxia is getting worse. We are in the process of preparing a publication to be submitted to the journal *Nature*. For this manuscript, we have included colleagues from all around the Baltic Sea as co-authors, e.g. from Sweden, Finland, Russia, Estonia, Latvia, Lithuania, Poland, Germany and Denmark, representing authorities, universities, monitoring agencies and private companies.

However, one of our initial goals was to determine the area of the bottom that suffers from hypoxia, which we were never able to achieve. Although there are a large number of sites that have been monitored, they are only a few monitoring sites in each area. In addition, many of these systems have complex topography making it difficult to assume that hypoxia occurs at the same depths in different locations. Given these two constraints, it was impossible for us to come up with an accurate areal extent of hypoxia, as integrating over surface-area is virtually impossible given the topographical variability. Modeling will be the only tool that will be able to address the areal extent of hypoxia in the coastal zone of the Baltic Sea, provided a detailed bathymetric charts are available for the bottom areas. This is currently not the case because of restrictions due to security requirements. For some specific regions, however, such maps are being released, and thus modeling-efforts will follow.

Nutrient retention

There are only a handful of case studies in the Baltic Sea that have determined coastal nutrient retention. It was our original intention in the project to determine the removal of nutrients in the coastal zone at the scale of the Baltic Sea. Numerous studies have shown that hypoxia leads to phosphorus release from sediments and a loss of denitrification potential. Our plan was to use the coastal data assembled to also address the potential for nutrient retention in sediments. Once again, given the tremendous success we achieved in assembling a coastal database also meant that we have an overwhelming amount of data to analyze. In addition, the nutrient data is in much poorer condition than the oxygen data. There are many more missing values and there has been a wide variety of methods to analyze for nutrients in the coastal zone, varying in time and space. The HELCOM guidelines for chemical analysis and reporting of data do not exist in the coastal zone database. It will require considerable more effort in working with the database if we

are to make progress in determining nutrient retention in the coastal zone of the Baltic Sea. It is worth noting, however, that there are currently projects emerging that will, on a regional scale, address these specific issues.

Recommendations for restoration efforts

Our previous *Baltic Sea 2020* project suggested that if restoration efforts are to be undertaken in the Baltic Sea they should be focused in the coastal zone due to the ginormous scale of the problem with hypoxia in the open Baltic Sea. In our present analysis we classified the occurrence of hypoxia in the coastal zone into four different categories: *No Occurrence, Episodic, Seasonal and Persistent*. Restoration for hypoxia is obviously not necessary in areas with *No Occurrence* of hypoxia. In addition, it would be difficult to focus remediation on a system that has only episodic periods of hypoxia, unless those periods were frequent and known. And actually, there are very few areas with *Persistent* hypoxia, and of those most are located in deep, isolated "fjords" that have properties (physical shape, water exchange) that help keep it in a hypoxic condition and would be difficult to make them oxic and keep those ecosystem oxic.

The most logical place to focus restoration would be in areas of concern that are *Seasonally* hypoxic where mitigation would have the most significant impact. In these areas, phosphorus is probably seasonally stored in sediments during periods when the system is oxic and then released during hypoxia and the losses of nitrogen are also probably strongly tied to hypoxia (Conley et al. 2007. *Ecological Applications* 17: 165-184). The majority of areas with seasonal hypoxia occur in the archipelagos. These areas are actually not located in proximity to nutrient loads, e.g. they are dominated by nutrients from diffuse sources that make it difficult to identify the most cost-effective areas to focus restoration efforts in the Baltic Sea. Currently there are a handful projects running that are testing potential remedies in Sweden, Finland and on Åland (primarily by one kind of pumping or another; none of these projects have to date shown any successful results, and we are invited and actively participating in the evaluation process of these projects).

Figure 1. Areas where hypoxia has occurred in the coastal zone of the Baltic Sea.