Abschlussbericht

ERANET BONUS: Verbundprojekt BONUS-112: INFLOW – Rekonstruktion von Änderungen der Einstromintensität salzreichen Nordseewasseres in die Ostsee während des Holozans, Reaktionen des Ökosystems und Zukunftsszenarien

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BONUS SCIENCE FOR A BETTER FUTURE OF THE BALTIC SEA REGION

BONUS INFLOW

Project acronym: INFLOW - Holocene saline water inflow changes into the Baltic Sea, ecosystem responses and future scenarios

Reporting period: 2011 (2009-2011)

Project Partners

INFLOW (2009-2011) (http://projects.gtk.fi/inflow/index.html) was one of the BONUS research programme (http://www.bonusportal.org/) projects and it was funded by national funding agencies, the EU Commission and participating institutes. The Geological Survey of Finland (GTK) coordinated the INFLOW project that had nine partners in seven countries of the Baltic Sea Region:

Germany: **Leibniz Institute for Baltic Sea Research Warnemünde - IOW**,

Denmark: **Geological Survey of Denmark and Greenland - GEUS**,

Sweden: **Department of Earth and Ecosystem Sciences – Division of Geology, Lund University,** and **Swedish Meteorological and Hydrological Institute – SMHI**,

Poland: **Faculty of Earth Sciences, Department of Paleoceanology, University of Szczecin**,

Norway: **Unifob AS, Bjerknes Centre for Climate Research - BCCR**,

Russia: **A.P Karpinsky Russian Geological Research Institute – VSEGEI**,

Finland: **GTK, and Department of Geosciences and Geography, University of Helsinki**

Individual scientists that participated in the INFLOW project are shown in Appendix I

Project Structure

The INFLOW project consisted of 4 Work packages (WP); namely WP1-Sediment proxy studies, WP2-Modelling approach, WP3-Synthesis and WP4-Training and Education.

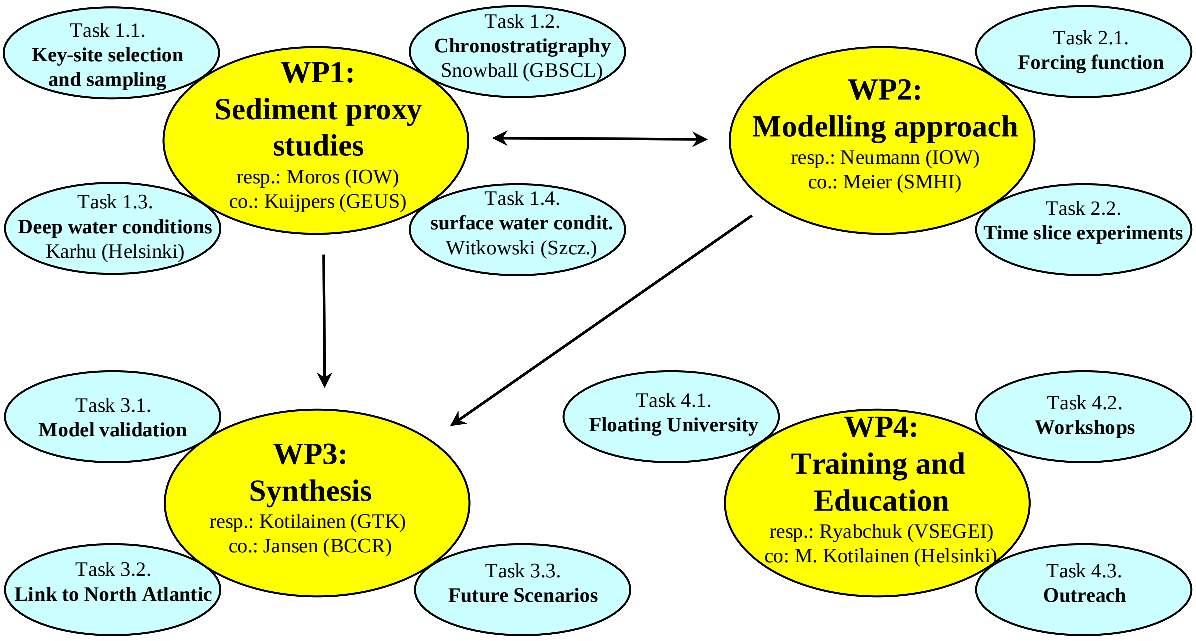

Figure 1. INFLOW Project Work packages (WP), Tasks and responsible persons.

Used resources

Used resources (person months) by each participating institute are shown in Appendix I.

Executive summary

Global climate change, growing population and increased activities in marine and coastal areas have threatened the marine environment worldwide. This deteriorating is valid also for the Baltic Sea, the European inland sea. The environmental problems of the Baltic Sea include e.g. eutrophication, seafloor hypoxia and increased chemical pollution. Considerable efforts to save and restore the condition of the Baltic Sea have been made during the past decades, but there is still work to do to ensure the health of our sea in future. In particular, it has been hypothesized that ongoing global warming and consequent climate changes may amplify the existing environmental problems that the Baltic Sea suffers from.

Effective and sustainable marine management and more plausible scenario simulations of the future Baltic Sea depend on improved understanding of the natural variability of the Baltic Sea ecosystem and its response to climate and human induced forcing.

The INFLOW project has used integrated sediment multi-proxy studies and modelling to reconstruct past changes in the Baltic Sea ecosystem (e.g. in saline water inflow strength, salinity, temperature, redox and benthic fauna activity) over the past 6000 years, concentrating on the last 1000 years that covers two natural climate extremes of the Little Ice Age and the Medieval Climate Anomaly; and the Modern Warm Period. The aim has been to identify the forcing mechanisms of those environmental changes, and to provide scenarios of the impact of climate change on the Baltic Sea ecosystem at the end of the 21st century AD.

Geological records of the Baltic Sea, especially sediments that have accumulated nearly continuously on the seafloor, provide unique information on past environmental changes. INFLOW has used a lot of efforts and resources to provide best possible material for sediment proxy studies. Several expeditions to the Baltic Sea have been organized during the project to collect material needed. Nearly hundred sediment cores were recovered during the expeditions from numerous carefully selected sites, along a transect from the marine Skagerrak to the freshwater dominated northern Baltic Sea.

INFLOW has studied ongoing and past changes in both surface (e.g. temperature and salinity) and deep water (e.g. oxygen and salinity) conditions and their timing. Sediment proxy studies included methods like TEX_{86} (a biomarker) for sea surface temperature, strontium isotopes ($^{87}Sr/^{86}Sr$) of bivalve shell carbonate and diatoms for salinity, and sediment fabric/trace fossils for benthic fauna activity reconstructions. In addition INFLOW has employed stable isotopes (O, C), Br, foraminera, dinoflagellate and mineral magnetic analysis among others. Geochemical methods included also XRF scans and ICP-MS analysis. Sound chronological control is crucial for high-resolution palaeoenvironmental reconstructions. Thus INFLOW has used multi-proxy dating methods, applying a range of different techniques, like (i) $^{210}Pb/^{137}Cs$ dating, (ii) $AMS^{14}C$ dating, (iii) paleomagnetic dating, and (iv) OSL dating .

Modelling was done in close co-operation with sediment proxy studies. The regional climate model of the Rossby Centre (RCA3) has been used to downscale global climate simulations (ECHO-G) to the regional (the Baltic Sea) scale and to deliver lateral boundary conditions for the local ecosystem models. The better constrained ecosystem models (RCO-SCOBI and ERGOM) used in INFLOW provided simulated data (hydrographical and biogeochemical conditions) for extreme natural climatic conditions over the past thousand years (e.g. the Medieval Climate Anomaly and the Little Ice Age). These are partly forced with sediment proxy results such as a 2 K temperature change from the Little Ice Age towards the Modern Warm Period. Model experiments provided insight into the mechanisms triggering Baltic Sea ecosystem state changes as observed in sedimentary archives. Validated models have been used to provide scenarios of the Baltic Sea ecosystem state at the end of the 21st century for selected Intergovernmental Panel on Climate Change (IPCC) climate change scenario.

Results of natural past changes in the Baltic Sea ecosystem, received in the INFLOW project, provide a discouraging forecast for the future of the Baltic Sea: nutrients loads, among other, need to be reduced in the future too in order to minimise the effect of sea surface temperature changes

Sea surface temperature (SST) reconstructions, based on sediment proxy studies (TEX_{86} method), indicate 2-3 °C variability, between the Medieval Climate Anomaly, the Little Ice Age (1450-1850), and the Modern Warm Period. This variability is higher than expected. Oxic conditions in the Gotland Basin recorded in the sediments by various parameters have been also reconstructed by ecosystem models for the Little Ice Age. Around thousand years ago, during the Medieval Climate Anomaly, the sea surface temperature of the Baltic Sea was around at same level as today. An exception was the shallow water coastal environment where since the ending of the 20th century maximum temperatures appear occasionally to exceed those found for the Medieval Climate Anomaly. During the Little Ice Age the sea surface temperature of the Baltic Sea was 2-3 °C colder than today. The establishment of anoxic conditions in the deeper basins began parallel to the temperature rise from the Little Ice Age towards the Modern Warm Period. In shallower areas anoxic conditions were established much later. The INFLOW results highlight a strong effect of sea surface temperature changes on redox conditions in the central Baltic.

INFLOW's sediment studies reveal that the Medieval Baltic Sea was severely affected by oxygen depletion. On the other hand, seafloor oxygen conditions were improved during the Little Ice Age. Sediment records indicate an important new finding: during stable extreme conditions (warm: Modern Warm Period e.g. 1980-2010, Medieval Climate Anomaly, cold: peak Little Ice Age) there were less saline water inflows into the Baltic Sea. This is confirmed by modelling studies, where a proxy for saline water inflow events into the Baltic Sea, based upon sea level pressure gradients over the North Sea, is used to estimate changes of mean strength of inflow over the last millennium. It is obvious that saline water inflows increased in frequency and magnitude during climatic transitions. This might be linked to a change in the prevailing atmospheric North Atlantic Oscillation (NAO) system from a stable NAO+/- towards more unstable conditions. This aspect is still under investigation.

In addition, sensitivity studies of the Baltic Sea were performed with Baltic Sea models. It was shown that changes in the mean conditions do not have a large impact on bottom oxygen concentrations. This adds confidence that changes in the variability could have been more important for the increase of oxygen depletion in bottom waters during the Medieval Climate Anomaly than changes in the mean conditions. However, further studies are still necessary to elucidate the processes involved.

Future climate change is likely to affect the Baltic Sea marine environment. Modelling simulations suggest warmer air temperatures in the future, with an annual mean increase in the range of 2.7-3.8 K for 2070-2099 relative to 1969-1998 in the Baltic Sea region. It has been estimated also that the climate warming could increase precipitation (and river runoff) to the Baltic basin, as well as reduce the length of the ice season in the Baltic Sea. Oxygen depletion at seafloor has been estimated to expand, too. Furthermore, changes in hydrography and biogeochemical processes could affect the whole Baltic Sea ecosystem.

Anoxia/hypoxia is harmful for macro benthic fauna and flora. It also affects the ecosystem via internal loading. Extended seafloor anoxia could enhance the environmental problems by releasing toxic heavy metals and nutrients, like phosphorus, from the seafloor sediments, and thus intensify the harmful effects of eutrophication. These may affect marine ecosystem by reducing marine biodiversity as well as fish catch. However, reliable future scenarios on the effects of climate change to the Baltic Sea