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Baltica

http://www.geo.lt/geo/index.php?id=71C

BALTICA Volume 25 Number 2 December 2012 : 185–188
doi:10.5200/baltica.2012.25.18

Holocene saline water inflow changes into the Baltic Sea, ecosystem responses and future scenarios

Aarno T. Kotilainen

Kotilainen, A. T., 2012. Holocene saline water inflow changes into the Baltic Sea, ecosystem responses and future scenarios. *Baltica, 25 (2), 185-188.* Vilnius. ISSN 0067-3064.

Manuscript submitted 2 November 2012 / Published online 10 December *2012*

Abstract *The Holocene saline water inflow changes into the Baltic Sea* (INFLOW) was one of the BONUS Research Programme projects (2009–2011) that generate new knowledge in support of decision-making in the Baltic Sea region. The INFLOW project integrated sediment multi-proxy studies and modelling aiming to reconstruct past changes in the Baltic Sea ecosystem; 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. The main efforts have been directed towards studies of the saline water inflow strength, salinity, temperature, redox, and benthic fauna activity over the past 6000 years, concentrating on the time period that covers two natural climate extremes, the Little Ice Age and Medieval Climate Anomaly.

Keywords *The Baltic Sea • Sedimentation • Environmental change • Climate change • Holocene • Inflow • Multi-proxy analyses • Modelling •*

✉ *Aarno Kotilainen (aarno.kotilainen@gtk.fi), Geological Survey of Finland, P. O. Box 96, 02151 Espoo, Finland.*

INTRODUCTION

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 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 the 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.

To be able to provide more plausible scenario simulations of the future Baltic Sea, it is essential to improve understanding of the natural variability of the Baltic Sea ecosystem and its response to climate and human induced forcing. *The Holocene Saline Water Inflow Changes into the Baltic Sea* (INFLOW) project aimed to provide this essential information. INFLOW (2009–2011) *(http://projects.gtk.fi/inflow/index.html)* was one of the BONUS Research Programme *(http://www.bonusportal.org/)* projects that generate new knowledge in support of decision-making in the Baltic Sea region. INFLOW 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 around the Baltic Sea, from 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 Palaeoceanology, University of Szczecin; Norway: Unifob AS, Bjerknes Centre for Climate Research (BCCR); Russia: A. P. Karpinsky Russian Geological Research Institute (VSEGEI); and Finland: GTK and Department of Geosciences and Geography, University of Helsinki.

STUDY AREA AND METHODS

Study area of the INFLOW project covers the Baltic Sea, from the marine Skagerrak to the freshwater dominated northern Baltic Sea and the Gulf of Finland (Fig. 1). Geological records of the sea, especially muddy 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 from carefully selected key sites for sediment proxy studies. Several expeditions (e.g. onboard *R/V Maria S. Merian, R/V Professor Albrecht Penck, R/V Ladoga, R/V Aranda and R/V Risk)* have been organized during the project to collect material needed (Fig. 2). Nearly hundred sediment cores (including gravity cores, piston cores and different types of surface sediment cores) were recovered during the expeditions from numerous carefully selected sites (Kotilainen *et al.* 2012).

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 (Kabel *et al.* 2012), strontium isotopes ($^{87}Sr/^{86}Sr$) of bivalve shell carbonate and diatoms for salinity, and sediment fabric/trace fossils for benthic fauna activity reconstructions (Virtasalo *et al.* 2011a, 2011b).

In addition INFLOW has employed stable isotopes (O, C), Br, foraminifera, 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) optically stimulated luminescence (OSL) dating. In addition, for subsurface sediments oceanographic (e.g. Major Baltic Inflows 1993 and 2003) and biological monitoring data were used to identify further stratigraphic tie points during the Modern Warm Period (the past 130 years or so). For the first time, this high-resolution chronology enables linking instrumental (monitoring) and sediment proxy data.

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 (MCA) ~950–1250 AD and the Little Ice Age (LIA) ~1350–1850 AD).

These are partly forced with the sediment proxy results such as a 2°C surface water temperature increase from the Little Ice Age towards the Modern Warm Period. Model experiments provided insight into the mechanisms triggering Baltic

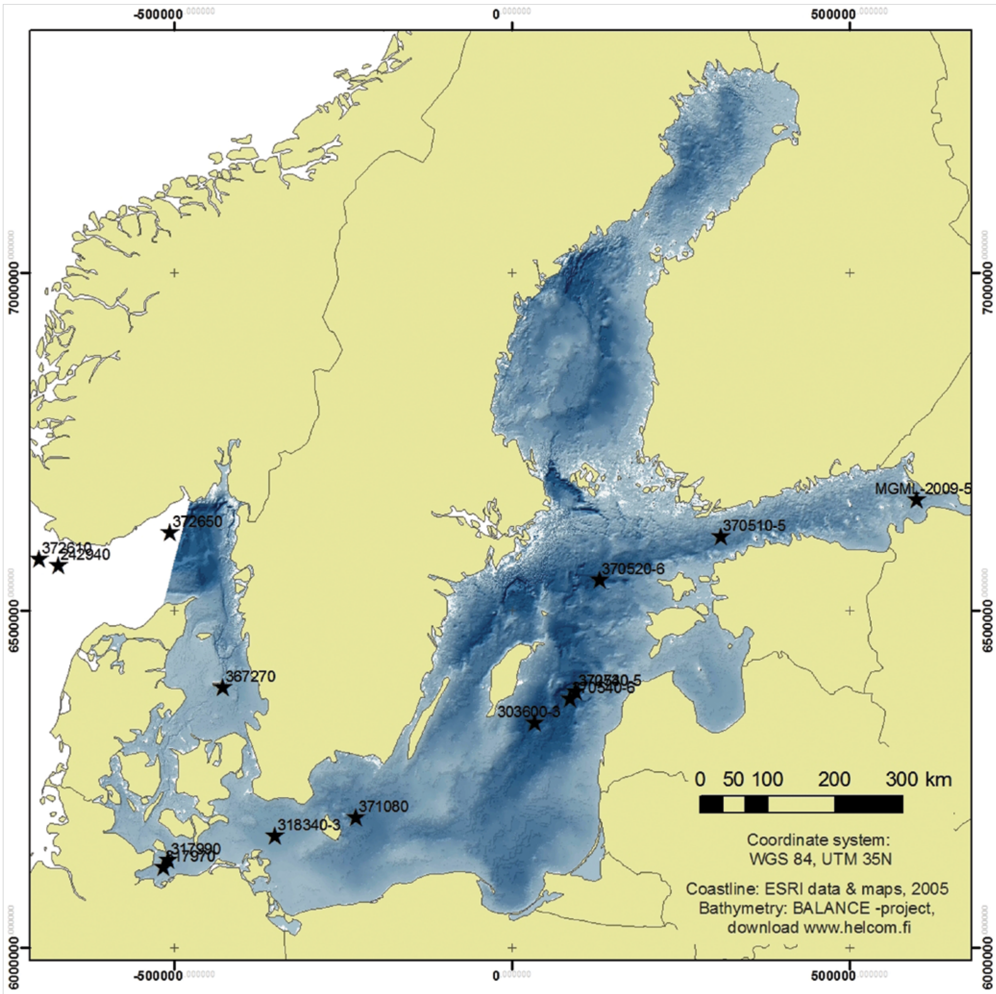

Fig. 1 Survey area of the INFLOW project, key sites studied in the Baltic Sea and sediment core ID numbers; bottom topography is shown after BALANCE Interreg IIIB EU project, 2009/ (after Kotilainen *et al.* 2012, Fig. 4).

Fig. 2 Long gravity corer (IOW, 9 m) in use onboard *R/V Aranda* during INFLOW cruise in the Gotland basin. Photo by A. Kotilainen, April 2009.

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.

KEY RESULTS AND DISCUSSION

Besides the improved geochronology, multi-proxy dating methods used in the INFLOW project allowed the inference of radiocarbon reservoir ages (delta R) (Lougheed *et al.* 2012). OSL dating was also tested during the INFLOW project. Results indicated complete bleaching and a great promise for this dating technique for marine fine grained sediments.

The new results of natural past changes in the Baltic Sea ecosystem, received in the INFLOW project, provide a discouraging forecast for the future of the sea. Integrated modelling and sediment proxy studies reveal increased sea surface temperatures and extended seafloor anoxia (in deep basins) also during earlier natural warm climate phases such as the Medieval Climate Anomaly. 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 and the Modern Warm Period (Kabel *et al.* 2012). The INFLOW project has shown that there is strong natural variability, higher than expected, at millennial to multi-decadal timescale which will have some impact on the future Baltic Sea.

New methods used in the project included also detailed sedimentological and ichnological analyses of sediment X-radiographs. Those were used, for the first time in the Baltic Sea, for reconstructing basin-scale changes in the distribution and functional complexity of macrozoobenthic communities in response to salinity and oxygenation variability during the past several millennia (Virtasalo *et al.* 2011a, 2011b). Fe and S isotope microanalyses of pyrite-filled worm-burrows provided significant new insight into the relative importance of bacterial sulfate reduction and microbial iron reduction in organic-C mineralization during progressive burial (Virtasalo *et al.* 2010, 2012).

Modelling and sediment proxy results suggest that under future IPCC scenario of a global warming there is likely no improvement of bottom water conditions (Meier *et al.* 2011). Thus, the already taken measures towards a better Baltic Sea are insufficient to guarantee a healthier future for the Baltic Sea. Therefore nutrient loads, among other, need to be reduced in the future too in order to minimize the effect of sea surface temperature changes.

CONCLUSIONS

The INFLOW project has used integrated sediment and modelling studies to deepening scientific knowledge and understanding about the factors affecting the long-term changes in marine environment and of possible future changes of the Baltic Sea. That information will provide basis for improved management, implementation of policy strategies (e.g. the European Marine Strategy Directive) in the Baltic Sea environmental issues and adaptation to future climate change.

Summing up the climate change (IPCC scenarios of global warming), increasing human activities and human induced loading, the already taken measures are not sufficient. Further actions are needed including substantial nutrient load reductions also in the future in order to minimize the effect of sea surface temperature changes.

Despite the new findings of the INFLOW project, several research topics need to be studied in future. Those include ^{14}C dating of the Baltic Sea sediments due to radiocarbon reservoir effect. Also fine grain OSL dating method needs to be further improved. One of findings of the INFLOW project was that saline water inflows enhanced during climatic transitions. That might be linked to a change in the prevailing atmospheric North Atlantic Oscillation (NAO) system from a stable NAO +/– towards more unstable conditions, but that need to be studied further also.

Precipitation changes over the past thousand years, and it effects on the Baltic Sea ecosystem remains still unsolved. Future scenarios on the effects of climate change to the Baltic Sea ecosystem and biodiversity are difficult to produce due to complicated ”cause–effect” relationships, and further studies are needed also in this topic. The INFLOW project ended in 2011, but there is still a lot of research going on with the INFLOW data, and results and publications to come in the near future.

Acknowledgements

This study is part of the INFLOW project, funded by the European Commission 7th Framework Programme (FP/2007–2013) under Grant agreement No. 217246 made with BONUS, the joint Baltic Sea Research programme, and by the Academy of Finland.

Scientists of the INFLOW partner organisations who have made a major contribution are: Thomas Neumann, Antoon Kuijpers, Markus Meier, Ian Snowball, Andrzej Witkowski, Eystein Jansen, Daria Ryabchuk, Juha Karhu, Joonas Virtasalo, Karoline Kabel, Thomas Leipe, Matthias Moros, Christian Porsche, Niels Poulsen, Jens Peter Rasmussen, Sofia Ribeiro, Francisca Staines-Urias, Kaarina Weckström, Bryan Lougheed, Kari Eilola, Robinson Hordoir, Zohreh Ranjbar, Semjon Schimanke, Gustav Strandberg, Slawomir Dobosz, Dagfinn Bøe, Björg Risebrobakken, Timofev Bodryakov, Andrey Grigoriev, Alexander Sergeev, Vadim Sivkov, Mikhail Spiridonov, Vladimir Zhamoida, Laura Arppe, Malviina Hallamaa, and Mia Kotilainen.

References

Kabel, K., Moros, M., Porsche, C., Neumann, T., Adolphi, F., Andersen, T. J., Siegel, H., Gerth, M., Leipe, T., Jansen, E., Sinninghe Damsté, J. S., 2012. Impact of climate change on the health of the Baltic Sea ecosystem over the last 1000 years. *Nature Climate Change,* published online 1 July 2012; http://dx.doi.org/10.1038/nclimate1595

Kotilainen, A., Neuman, T., Kuijpers, A., Meier, H. E. M., Snowball, I., Witkowski, A., Jansen, E., Ryabchuk, D., Karhu, J., Virtasalo, J., Moros, M., Leipe, T., Kabel, K., Porsche, C., Poulsen, N., Rasmussen, J. P., Ribeiro, S., Lougheed, B., Eilola, K., Hordoir, R., Schimanke, S., Strandberg, G., Dobosz, S., Risebrobakken, B., Bodryakov, T., Grigoriev , A., Spiridonov, M., Sergeev, A., Sivkov, V., Zhamoida, V., Arppe, L., Hallamaa, M., Kotilainen, M., 2012. *INFLOW Final Report 2009–2011.* INFLOW Interim Report No. 8, Espoo, GTK, 75 pp. Electronic publication: http://projects.gtk.fi/inflow/index.html

Lougheed, B. C., Snowball, I., Moros, M., Kabel, K., Muscheler, R., Virtasalo, J. J., Wacker, L., 2012. Using an independent geochronology based on palaeomagnetic secular variation (PSV) and atmospheric Pb deposition to date Baltic Sea sediments and infer ^{14}C reservoir age. *Quaternary Science Reviews 42*, 43–58. http://dx.doi.org/10.1016/j.quascirev.2012.03.013

M eier, H. E. M., Andersson, H. C., Eilola, K., Gustafsson, B. G., Kuznetsov, I., Müller-Karulis, B., Neumann, T., Savchuk, O. P., 2011. Hypoxia in future climates: A model ensemble study for the Baltic Sea. *Geophysical Research Letters, Vol. 38,* L24608; http://dx.doi.org/10.1029/2011GL049929

Virtasalo, J. J., Löwemark, L., Papunen, H., Kotilainen, A. T., Whitehouse, M. J., 2010. Pyritic and baritic burrows and microbial filaments in postglacial lacustrine clays in the northern Baltic Sea. *Journal of the Geological Society London 167,* 1185–1198. http://dx.doi.org/10.1144/0016-76492010-017

Virtasalo, J. J., Leipe, T., Moros, M., Kotilainen, A. T., 2011a. Physicochemical and biological influences on sedimentary-fabric formation in a large, salinity and oxygen-restricted epicontinental basin: Gotland Deep, Baltic Sea. *Sedimentology 58,* 352–375. http://dx.doi.org/10.1111/j.1365-3091.2010.01166.x

Virtasalo, J. J., Bonsdorff, E., Moros, M., Kabel, K., Kotilainen, A. T., Ryabchuk, D., Kallonen, A., Hämäläinen, K., 2011b. Ichnological trends along an open-water transect across a large marginal-marine epicontinental basin, the modern Baltic Sea. *Sedimentary Geology 241*, 40–51. http://dx.doi.org/10.1016/j.sedgeo.2011.09.010

Virtasalo, J. J., Whitehouse, M. J., Kotilainen, A. T., 2012. Iron isotope heterogeneity in pyrite fillings of Holocene worm burrows. *Geology,* published online 15 October 2012; http://dx.doi.org/10.1130/G33556.1