Technical Report No. 6

Long-term reconstruction of nutrient loads to the Baltic Sea, 1850-2006

June 2012

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Baltic Nest Institute

The Baltic Nest Institute

The Baltic Nest Institute host the Nest model, a decision support system aimed at facilitating adaptive management of environmental concern in the Baltic Sea.

Nest can be used to calculate required actions needed to attain politically agreed targets for the Baltic Sea ecosystem. By modeling the entire drainage area, Nest is a novel tool for implementing the ecosystem approach in a large marine ecosystem. The main focus of the model is on eutrophication and the flows of nutrients from land to sea.

Reducing the nutrient input to the sea and thus decreasing the negative environmental impacts is a politically prioritized area of international cooperation. Baltic Nest Institute can contribute to this process by formulating policies that are fair, transparent and cost-efficient. The main target group for the Nest Decision Support System is HELCOM and regional water directors in the riparian countries.

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1. Introduction

A common intention in ecosystem approach to management of marine resources worldwide has become a ‘restoration of ecosystems’ to some better shape. Although appealing, this political, rather vague aim has to be made more precise in order to be useful as a management objective. Therefore, a crucial role in defining EO, EQS, ES, ET, and similar characteristics set forward by, e.g. BSAP, MSFD, ND, UWWTD, and WFD as well as by many other acronyms to come, belongs to some conventional numbers that are considered as representing so-called background or reference conditions, which existed before significant man-made disturbances. At the Baltic Sea, experiencing human influence for centuries, quantification of the reference conditions and designing of desired state of restored marine ecosystems is complicated by both the uncertainty of which past times might be considered as reference times and the lack of essential observations from those times.

One of the major, if not the only reliable method for reconstruction of the reference trophic state is it’s simulation with biogeochemical models forced by the appropriate boundary conditions, including external nutrient inputs corresponding to the reference time interval. Once reconstructed, estimates of such “pristine” or, better to say, “pre-industrial” loads and their historical development can also be used both to test models’ capabilities in reproducing pre-eutrophied state of the Baltic Sea and to study the very development of its eutrophication. Plausible solution of these problems gives more credibility to simulated responses of the marine ecosystems to scenarios of load reductions.

For the Baltic Sea, such approach was initiated by Schernewski and Neumann (2005) and Savchuk et al. (2008) and further developed in the ECOSUPPORT Project (Gustafsson et al., 2012), where also a reconstruction of nutrient inputs since 1850 was briefly described. In order to facilitate distribution of reconstructed inputs and their usage, here we describe the process of reconstruction in more detail and make available the full data sets in digital form. The reconstructed external nutrient inputs comprise two periods. Land loads and atmospheric deposition in 1970-2006 are based on the best available data with sufficiently high coverage and resolution (Savchuk et al., 2012), while temporal dynamics over 1850-1970 were interpolated between estimates prescribed for a few fixed years. Similarly to the dataset for 1970-2006, the reconstructed inputs are aggregated according to the spatial segmentation of the Baltic Sea (Fig. 1) currently implemented in the biogeochemical model BALTSEM (BAltic sea Long-Term large Scale Eutrophication Model).

2. River loads

The reconstruction of riverine nutrient loads during 1970-2006 into BALTSEM basins is described in detail by Savchuk et al. (2012). For the lack of information covering the entire Baltic Sea watershed, nutrient inputs for 1850-1970 were piece-wise linearly interpolated between only four “reference” points in time: loads prescribed for 1850, 1900, 1950, and as a five-year average of 1970-1974 (Table 1).

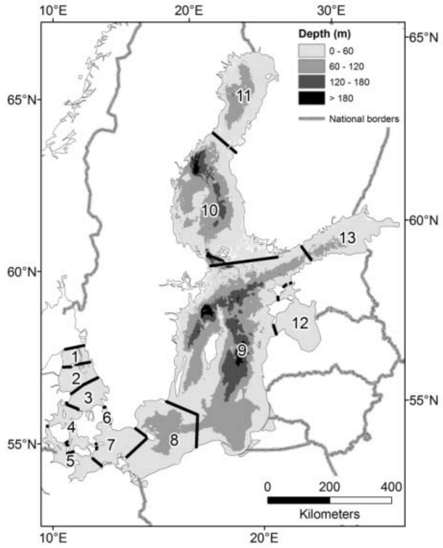

Fig. 1. The Baltic Sea partitioning into thirteen BALTSEM basins.
1 – Northern Kattegat (NK), 2 – Central Kattegat (CK), 3 – Southern Kattegat (SK), 4 - Samsø Belt (SB), 5- Fehmarn Belt (FB), 6 – Öresund (OS), 7 – Arkona basin (AR), 8 – Bornholm basin (BN), 9 – Gotland Sea (GS), 10 – Bothnian Sea (BS), 11 – Bothnian Bay (BB), 12 – Gulf of Riga (GR), 13 – Gulf of Finland (GF); hereafter Kattegat (KT) comprises NK, CK, and SK, Danish Straits – SB, FB, and OS, Baltic Proper – AR, BN, and GS.

Pre-industrial river loads for **1900** are based on estimates by Savchuk et al. (2008). Ignoring chronological differences between countries, we consider 1950 as a year when Europe resumed its demographical and economical development that had been interrupted and greatly set back by the World War II. In terms of nutrient load generation, the development during these two decades of the 1950s and 1960s was remarkable both globally and within the Baltic Sea Region (e.g., Clarke, 2006; Jansson and Dahlberg, 1999; de Wit et al., 2011). Intensification of the agriculture caused by both mechanization and greatly increasing application of fertilizers (e.g., Eglin et al., 2010; Eriksson et al., 2007; Kremser and Schnung, 2002) led to much larger increase in nutrient input from the southern agricultural landscapes of Denmark to Poland than from the vast forested areas of Northern Finland and Sweden. These inter-basin differences have been taken into account when prescribing riverine nutrient inputs for the year **1950** as an intermediate breaking point between the 1900 and 1970 (Table 1). For simplicity, the increase of loads between **1850** and 1900 was assumed to be proportional to the load increase between 1900 and 1950.

Finally, the decomposition of annual integrals interpolated between “reference” years into monthly loads was made with the average seasonal patterns estimated for the same 1970 – 1975.

Table 1. Reconstructed annual riverine loads of nutrients

Year	BB	BS	BP	GF	GR	DS	KT	Total
Total nitrogen (t yr^{-1})								
1850	35,899	32,705	147,883	58,200	32,027	10,041	18,073	334,828
1900	36,079	33,126	163,601	58,153	32,900	10,933	19,126	353,919
1950	36,271	33,578	183,926	59,694	33,936	11,956	20,324	379,684
1970	38,758	41,418	467,377	78,306	91,920	35,834	50,017	803,630
2000	70,093	68,707	273,693	95,841	65,194	35,839	72,082	681,448
Total phosphorus (t yr^{-1})								
1850	955	906	2,546	1,581	472	511	716	7,687
1900	983	938	4,020	2,243	672	546	743	10,145
1950	1,011	971	6,509	3,186	997	584	771	14,029
1970	2,473	2,231	18,674	7,091	3,859	1,426	1,423	37,177
2000	3,529	3,022	18,467	5,559	3,965	896	1,658	37,096

Note: Loads in the 1850, 1900, and 1950 were prescribed in this report, while compilation of the loads for the 1970 and 2000 is described by Savchuk et al. (2012) and given here for a comparison

3. Direct point sources

Nutrient loads from the large coastal cities reconstructed by Savchuk et al. (2008, 2012) have been updated and re-evaluated with information on the dynamics of urban population (Anonymous, 2006) assuming annual nutrient excretion rates of 3.3. kg N and 0.4 kg P per capita (Meybeck et al., 1989) and no change between 1850 and 1900 (Fig. 2).

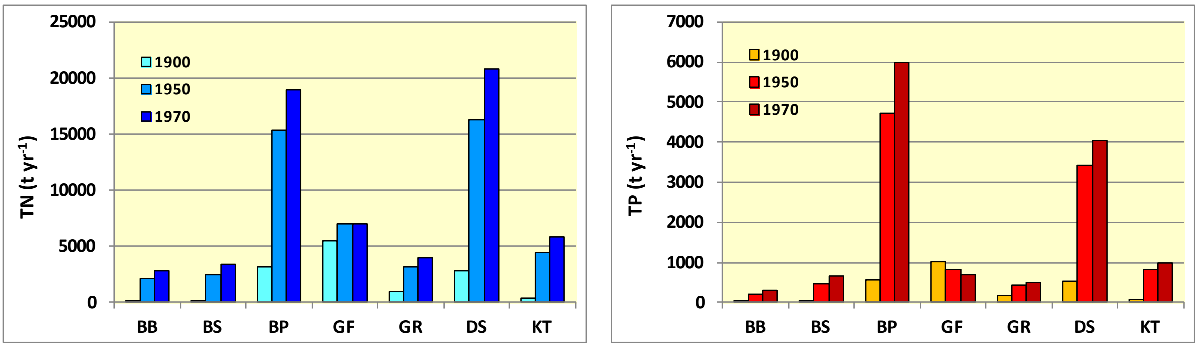

Fig. 2. Nitrogen (left) and phosphorus (right) inputs
into the Baltic Sea basins from the direct point sources.
For abbreviated basin's names see Fig. 1

4. Atmospheric depositions

For 1970-2006, basin-wise monthly time series of the nitrogen atmospheric deposition were compiled at the Baltic Nest Institute (BALTSEM dataset, Savchuk et al., 2012) combining estimates based on measurements (Granat, 2001) with simulations performed within the Cooperative Programme for Monitoring and Evaluation of the Long-range Transmissions of

Air Pollutants in Europe (ECE/EMEP) (e.g. Bartnicki et al., 2008, 2011). The reconstruction of the historical time series for 1850-1969 was also made by a linear interpolation between a few selected "reference" years, for which atmospheric deposition was estimated from available data (Ruoho-Airola et al., 2012). The core data set of historical measurements until the 1940s included fragmented observations since 1852 from 11 stations located in source areas for the atmospheric load to the Baltic Sea, including many important sites outside the Baltic Sea watershed, e.g. at the British Isles. For the 1950s and 1960s, data from the dense European Air Chemistry Network (EACN) with common methods were utilized (Egner and Eriksson 1955).

Years 1850, 1900, 1925, 1950, 1960 and 1970 were selected as turning points in the time series of the atmospheric nitrogen load. The annual deposition of total inorganic nitrogen (IN_{tot}) for these years was estimated from the core historical data and assessments in the literature. The estimate for IN_{tot} deposition was then split into reduced and oxidized nitrogen fractions based on the ratio of these components both in the historical observations and EMEP's model results. Because the core data of historical measurements included mainly the wet fraction of nitrogen deposition, the dry fraction of deposition was added from modeled estimates of the ratio between dry and wet deposition. Further, the reconstructed annual depositions were decomposed into monthly values by multiplication with twelve dimensionless fractions of annual integrals estimated from the BALTSEM data set. Reconstructed long-term dynamics of annual IN_{tot} deposition is presented in Fig. 3. Note also, that the increase of reconstructed IN_{tot} deposition from the 1900 to the 1970s-1980s of about five-six times is smaller than the ten-fold increase assumed by Schernewski and Neumann (2005) and adopted from them by Savchuk et al. (2008). In other words, our new estimates suggest that in the past the atmosphere could have been a more significant source of nitrogen for the Baltic Sea than was assumed in the earlier studies.

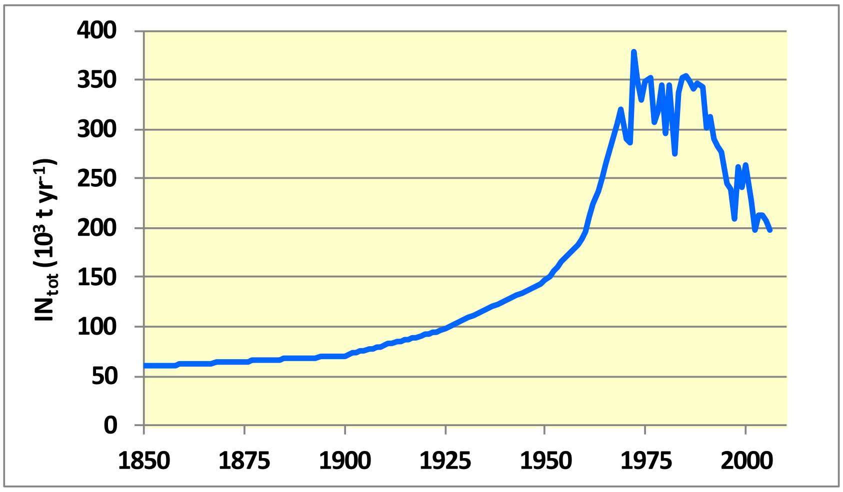

Fig. 3. Annual integrals of inorganic nitrogen atmospheric deposition on the entire Baltic Sea

Because no reliable monitoring results of the atmospheric deposition of phosphorus covering the period studied was found, on the base of published ranges the atmospheric phosphorus load was assumed to be 15 kg P km^{-2} yr^{-1} invariably and evenly deposited over the entire Baltic Sea during 1970-2006 (Ruoho-Airola et al., 2012 and references therein). According to Mahowald et al. (2008), the historical increase of phosphorus deposition was less pronounced than the increase of nitrogen deposition, and deposition in 1850 was assumed to be only a half of that in 1970.

5. Integral nutrient inputs

According to presented reconstruction, since the 1850 the Baltic Sea has received from the land and atmosphere about 100 million tonnes of nitrogen and 4.5 million tonnes of phosphorus, over half of it during the past fifty years (Table 2).

Table 2. Integral nutrient loads to the Baltic Sea

	1850 – 1899	1900 - 1949	1950 – 1999	1850 - 2000
Nitrogen (tonnes)	20,653,845	25,047,388	51,541,870	97,243,103
Phosphorus (tonnes)	668,231	1,117,472	2,636,237	4,421,940

6. Acronyms

BSAP – Baltic Sea Action Plan

EO – ecological objectives

EQS – environmental quality standard

ES – ecological status

ET – ecological targets

MSFD – Marine Strategy Framework Directive

ND – Nitrate Directive

UWWTD – Urban Waste Water Treatment Directive

WFD – Water Framework Directive

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