Causes and consequences of the Baltic Sea hypoxia: the vicious circle revisited with models

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Summary
Long-term dynamics of the Baltic Sea offshore hypoxia is governed by interplay between a sporadic natural aeration of the deep waters and man-enhanced oxygen demand. Variations of hypoxic zone bring forth biogeochemical alterations of the nitrogen and phosphorus pools interlocked in positive feedback where hypoxia is sustained with mineralization of primary production based on nitrogen fixed by cyanobacteria thriving on a P excess. The ecosystem consequences of these interactions are quantified with an aid of both extensive databases and simulations with mathematical models.

Introduction
Large-scale offshore hypoxia and its biogeochemical effects are the inherent natural properties of the Baltic Sea (e.g., Savchuk, 2010 and references therein). Particularly important in the brackish Baltic Sea is the “vicious circle”: inorganic nitrogen removal due to denitrification and phosphate release from the anoxic bottoms result in the Redfield excess of DIP that forces dinitrogen into biotic cycling via nitrogen-fixing cyanobacteria thus increasing primary production, sedimentation and decomposition of organic matter, which, in turn, leads to further expansion of hypoxic zone with increased denitrification and DIP release (Vahtera et al., 2007). Shrinking of the hypoxic zone after sporadic MBIs causes opposite changes of the N and P pools. Together with fishery, the coupled variations of hypoxic zone and biological productivity affect the fish population dynamics.

Materials and Methods
Time-series of the basin-wide hypoxia indicators and nutrient pools are estimated from extensive distributed databases (Acknowledgement, 2015) with DAS (Sokolov et al., 1997) and Nest (Wulff et al. 2013) tools. Analysis of ecosystem interactions and quantification of integral biogeochemical fluxes are made with a help of SANBALTS (Savchuk and Wulff, 2007), BALTSEM (Savchuk et al. 2012, Gustafsson et al. 2012) and SANFISH (Savchuk and Tomczak, 2014) mathematical models.

Results and Discussion
Long-term dynamics of the basin-wide annual means of DIN and DIP are related to changes of redox conditions (Figure 1A) and result in corresponding variations of DIN:DIP ratio as an indicator of phosphorus excess favouring summer cyanobacteria blooms (Figure 1B).

Figure 1. Variations of nutrients, hypoxic area (HA, O₂ < 2 ml L⁻¹), DIN:DIP ratio, and total area of cyanobacteria accumulations (TCA, Kahru and Elmgren 2014) in the Baltic Proper.

Appropriate description of these interactions in the mechanistic biogeochemical models resulted in well comparable behaviour of the simulated and observed pools (Figure 2), thus justifying
implementation of the models for hindcast estimates and scenario projections, including BSAP.

Figure 2. Relationships between simulated and "observed" hypoxia indicators and annual mean pools of DIN (A) and deep-water (>60m) DIP (B) in the Baltic Proper.

Using outputs from the biogeochemical models as food for fish (zooplankton and benthos), those scenarios have also been expanded over the major offshore fish stanzas (Figure 3).

Figure 3. Biomasses of the major offshore fish stanzas in the Baltic Proper: comparison with reconstructions from ICES Assessment 2013 for 1997-2003 (A) and scenarios of the different trophic conditions (B).

References


