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Alterations in nutrient limitations — Scenarios of a changing Baltic Sea

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Abstract

Previous trend studies have shown increasing nitrogen and phosphorus as well as decreasing silica concentrations in the water mass of the Baltic Sea. This has had an impact on the amount of primary production, but also on the quality and succession of plankton species. Present study examines the spatial and temporal patterns of potential nutrient limitations in the Baltic Sea for the time period 1970–2000. Generally, low concentrations of DSi can limit the diatom blooms and such conditions are found in the Gulf of Riga and Gulf of Finland during spring and summer. Nutrient ratios, DSi:DIN, DSi:DIP and DIN:DIP, are often used to determine which nutrient may limit the primary production. Annual long-term temporal trends of silica to inorganic nitrogen and phosphorus respectively show consistent decreasing patterns. The largest slopes are detected during spring and summer for DSi:DIN and during spring for DSi:DIP ratios. For the DIN:DIP ratio significant slopes are only found in a few locations despite increasing levels for both nutrients, displaying a large variation in trends. In the open Baltic Proper the present trends are positive during winter and negative during spring and autumn. Gulf of Finland and Gulf of Riga are areas where both DSi:DIP and DSi:DIN ratios are found close to the Redfield ratios for diatoms. Together with the evaluated trends these suggest that the Gulfs may become silica limited in a relatively near future. These findings give some implications on the development and impact of changing nutrient concentrations.

Keywords: DSi; DIN; DIP; Nutrient ratios; Redfield; Limitation; Trends; Baltic Sea

1. Introduction

Approximately one third of the global primary production is originated in marine waters and coastal waters representing 30–50% of the global oceanic new production (Paerl et al., 1995). The size of this production largely depends on the availability of inorganic nutrients, and the relationship between them. The average composition of carbon and nutrients assimilated in algae generally follows the molar ratio C_{106}:N_{16}:P_1, as first suggested by A.C. Redfield (see Redfield et al., 1963). However, the picture is more complex involving e.g. Fe (Blomqvist et al., 2004) as well as light and turbulence (Huisman et al., 2004). Deviations in pelagic nutrient concentrations from these proportions have been used as indicators of primary production limitation. While the nutrient ratios in oceanic water are close to the Redfield one (Tyrell, 1999), adjacent seas like the Baltic Sea deviate strongly from this ratio showing large regional and seasonal differences.

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Marine environments are often assumed nitrogen (N) limited (Nixon et al., 1996), while freshwaters are mainly thought of as phosphorus (P) limited (Schindler, 1974). This is not entirely true, and often both nitrogen and phosphorus are limiting depending on time of year and location.

The Redfield ratio was later extended to incorporate also silica; C_{106}:N_{16}:P_1: Si_{16} (Harrison et al., 1977). Silica (Si) is mainly used in forming diatom shells, but is also found in many terrestrial plants etc. In contrast to the two above-mentioned nutrients N and P it is not directly influenced by human activities as it originates from weathering in the form of dissolved silica (DSi). It is often assumed to be in excess compared to N and P. Damming usually decreases silica load significantly and recent evidences show that silica has become a potential limiting factor in some coastal waters (e.g. Conley et al., 2000). This limitation will affect the plankton composition, which in a longer perspective may change the entire food web (Humborg et al., 1997).

There is also a more long-term aspect to take into account. Globally the anthropogenic N input to coastal waters has increased by a factor of two to three over recent decades (Jickells, 1998). In the Baltic Sea, the corresponding N change is a factor four and for phosphorus the load had increased about eight times, mainly during the second half of the 20th century (Larsson et al., 1985). The Baltic Sea shows, due to this increased load, many signs of eutrophication (Rönnberg and Bonsdorff, 2004). Previous studies have found increasing trends of N and P and simultaneously decreasing trends of Si (Papush and Danielsson, 2006). Not surprising, decreasing coastal inorganic DSi:DIN ratios have also been observed (Rahm et al., 1996). Normally these changes have consequences also for the nutrient limitation patterns. Potential nutrient limitation has been studied for a long time in the Baltic Sea (e.g. Howarth, 1988; Granéli et al., 1990; Lignell et al., 1993). Changes in nutrient ratios, linked to a reduction of spring bloom diatoms, has already been observed (Wasmund and Uhlig, 2003). It has been found that the diatom spring bloom is often terminated by the onset of thermal stratification and depletion of, primarily, nitrogen (Smetacek, 1985; Heiskanen and Kononen, 1994). A reduced DSi load at the same time as progressing N and P loads, will result in changes in nutrient ratios with the potential to modify the species composition of the plankton community. Consequently, the present study focuses on the spatial and temporal patterns of potential nutrient limitation in the Baltic Sea. This is divided into two objectives — silica limitation by low concentration and alterations due to changing nutrient ratios. The findings are discussed in relation to the Redfield ratios along with possible implications on the ecosystem.

2. Data material and methods

2.1. Study area

The brackish Baltic Sea is located in Northern Europe (Fig. 1). It is a non-tidal, semi-enclosed water area, where shallow sills between the North Sea and Baltic Sea restrict the water exchange causing long hydraulic residence times — about three decades on average (Stigebrandt and Wulff, 1987). The circulation and mixing are mainly forced by wind stress and heat flux, which results in an anti-clockwise residual circulation in each major basin (Sjöberg, 1992). The freshwater discharge is limited and represents about half the brackish outflow (Wulff et al., 2001). These conditions result in an area with a well-mixed surface layer and a saline deep layer separated by a strong halocline. This halocline is well below the entrance sills to the North Sea and limits the recycling of nutrients and the supply of oxygen to the deep layers. Organic matter degradation often leads to hypoxia in these deep layers. Matthäus and Franck (1992) have shown how the infrequent major inflows govern the redox conditions in the deep basins in consort with the organic matter load.

2.2. Nutrient load and trends

The Baltic Sea is a shallow, brackish sea shared by 14 countries with a total drainage area about four times larger than the sea area. The population is ~85 million inhabitants, with the majority located in its southern parts (Sweitzer et al., 1996). This gives a north–south gradient in nutrient loads with up to four times higher loads in the southern parts related to the distribution of population, agricultural activities, major rivers and point sources. The Gulf of Finland is strongly influenced by the largest river in the Baltic Sea, Neva, and the largest coastal city, St Petersburg, while the Gulf of Riga receives its high nutrient load mainly from river Daugava and the city of Riga. The annual atmospheric deposition of dissolved inorganic nitrogen doubled during 1955–90, and now represents about a quarter of the total N input to the Sea (Granat, 1990; HELCOM, 2005). These loads have led to a significant increase in nutrient concentration in the water mass (Sandén et al., 1991; Sandén and Rahm, 1993; Kuparinen and Tuominen, 2001; Papush and Danielsson, 2006). The degradation in environmental quality has taken such proportions that an intergovernmental organisation, HELCOM, has been formed to counteract these problems. Today remedy actions have decreased the inputs of nutrients, e.g. by improved wastewater treatment (HELCOM, 2002).