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Societal, land cover and climatic controls on river nutrient flows into the Baltic Sea

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ABSTRACT

Study region: River basins draining into the Baltic Sea, known as the Baltic Sea Drainage Basin (BSDB).

Study focus: Dramatic shifts in water quality have been observed in the Baltic Sea in past decades. This study investigated the spatial distribution of trends in nitrogen (N) and phosphorus (P) in relation to societal, land cover and climatic changes. A 31-year record of observed catchment scale nutrient concentration and discharge data for the period 1970–2000 was combined with climate and land cover data. A Mann–Kendall test was applied to reveal trends in N and P, the N:P ratio, discharge, temperature and precipitation. Classical factor analysis and Kendall's rank correlation identified the most important relationships between nutrients, land cover and climate.

New hydrological insights for the region: A large spatial variability in N and P trends was observed with a notable difference between the east and west of the BSDB. The existence of regional trend variations are important for nutrient load reduction management strategies. Specifically, it is recommended that strategies targeting seawater eutrophication should focus more on P rather than N reduction because increasing P in the eastern catchments is responsible for the overall declining trend in the N:P ratio, an important trigger for algal blooms.

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1. Introduction

In past decades, dramatic shifts in water quality have been observed in the Baltic Sea. Problems occurring with such shifts include stagnation events that have resulted in anoxic bottom waters, the spreading of dead bottom zones and increased frequency and intensity of algal blooms (Boesch et al., 2006, 2008; Österblom et al., 2007; Vahtera et al., 2007; Voss et al., 2011). Of particular concern are blooms of toxic dinoflagellates and raphidophytes, which cause fish mortalities in both the wild and aquaculture (Boesch et al., 2006). More of these events are likely to occur in the future as the majority of projections point to increased nitrogen (N) and phosphorus (P) loads coming into the Baltic Sea in the 21st century (Graham and Bergström, 2001; Hägg et al., 2013; Reckermann et al., 2011). In addition to loads, it may be insightful to consider other indicators such as the N:P ratio which can also change under conditions where one nutrient is declining/increasing faster than the other. This in turn can cause algal blooms as different optimal N:P ratios exist for the growth of various algae (Anderson et al., 2002; Hodgekiss and Ho, 1997). As such, monitoring the water quality of the rivers that drain into the Baltic Sea is important as they directly influence the Sea's water quality state (Jansson and Stålvant, 2001). This is because the Baltic Sea has little water exchange with the North Sea, and as a result is more susceptible to anthropogenic impacts compared to other, more open, seas (Pastuszak and Igras, 2012; Pawlak et al., 2009). Therefore, it is important to understand and identify mechanisms that control the water quality in the catchments surrounding the Baltic Sea, known as the Baltic Sea Drainage Basin (BSDB).

Investigating possible mechanisms influencing the water quality of the rivers draining the catchments in the BSDB, however, is not straightforward as differences exist among the catchments in terms of societal, land cover and climatic characteristics (Graham and Bergström, 2001; Thorborg, 2012). Changes in society, land cover and climate can all lead to changes in the water quality of the catchments. Hägg et al. (2013) showed that regional anthropogenic effects are potentially more important for projecting nutrient load than climate change impacts. Anthropogenic effects are evident in a large part of the BSDB manifested through "the fall of the iron curtain" in 1989, which was an important societal change creating a clear transition period. During the transition period following the 1989 events, several fundamental shifts associated with livelihoods within the BSDB occurred including: (1) a drop in artificial fertilizer and manure application, (2) a decrease in livestock keeping, (3) closure of several factories, (4) improvements in farm management practices and (5) modernization of wastewater treatment plants all impacted the nutrient dynamics (Iital et al., 2005; Pastuszak et al., 2012). In addition, land cover change affected the hydrological cycle by altering infiltration, groundwater recharge, base flow and run-off in catchments (Lin et al., 2007; Todd et al., 2007). In the BSDB, conversion of wetlands into forests or agriculture have had significant impact on the terrestrial water balance as wetlands can maintain high discharges in dry periods of the year, which in turn alters flow regimes (Lyon et al., 2012; Van der Velde et al., 2013).

Climate change potentially influences water quality through several mechanisms. Temperature and precipitation change can cause changes in river flow regimes, which in turn affect hydrology and water quality. According to Wilson et al. (2010), a trend in temperature may cause long-term changes in the seasonal distribution of flow and in the magnitude and frequency of floods and droughts in Scandinavia. The same conclusion from model results was reported by Moore et al. (2008). Wright (1998) reported that an increase in temperature resulted in an increase in decomposition of organic matter leading to enhanced amounts of N in a river area in Norway. Similar observations were reported for P (Bowes et al., 2009).

Several regional studies have shown that changes in society, land cover and climate impacted the water quality of individual rivers in the BSDB in various ways (Hussian et al., 2005; Iital et al., 2005; Pastuszak et al., 2012). Recent modelling studies projecting future changes of nutrient loads into the Baltic Sea focused on the basin scale (Arheimer et al., 2014; Donnelly et al., 2014; Meier et al., 2012, 2014) whereas the Helsinki Commission (HELCOM) provided data on riverine nitrogen and phosphorus inputs on the basin to the sub-basin scale (e.g. HELCOM, 2011, 2013). The aforementioned modelling studies are often considered by policy makers when they formulate and implement management strategies. However, an overall spatial analysis on the catchment scale in the BSDB has not been presented yet. Such an analysis might reveal additional information which can lead to more focused