CLIMATE CHANGE LEADS TO THE FORMATION OF MASSIVE CYANOBACTERIAL BLOOMS IN THE HOLOCENE BALTIC SEA

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The modern Baltic Sea suffers from massive blooms of N_2-fixing heterocystous cyanobacteria that periodically develop during summer. Such blooms have significantly intensified over the recent past with drastic consequences for the health of the aquatic ecosystem as the massive export of cyanobacterial biomass from the photic zone has resulted in a four times increase in the area affected by bottom water hypoxia (dissolved oxygen < 2 mg/L) since the second half of the last century (Carstensen et al., 2014). As a consequence, the Baltic Sea turns into one of the world's largest dead zones with currently 65,000 km^2 being permanently depleted of oxygen leading to a dramatic loss of benthic faunal and floral communities, the reduction of fish populations and major alterations of biogeochemical cycles (Conley, 2012). The anthropogenic loading of nutrients (in particular of phosphorus) is considered to be a major driver for the recently observed increase in cyanobacterial activity but the environmental triggers that promote cyanobacterial bloom formation as well as the effect of such blooms on the spread of bottom water hypoxia in the Baltic Sea is presently only poorly understood.

At the Landsort Deep, a ca. 90 m-thick sediment sequence consisting of varved to homogeneous glacial clays and organic-rich mudstones were collected that for the first time allow investigating the relationship between cyanobacterial bloom formation and the spread of bottom water hypoxia in the Baltic Sea from the last deglaciation to the present-day. Total organic carbon values were generally low in the glacial clays (<0.5%) but at a depth of ca. 28 mcd (representing the transition from the Ancylus Lake to the Littorina Sea) significantly increased and showed three distinct maxima of up to 10% during the Holocene Thermal Maximum (HTM), the Medieval Climate Anomaly (MCA) and the Modern Hypoxic Period (MHP). Sediments deposited during these time intervals are well laminated and characterized by high total sulphur values indicating the development of anoxic to euxinic bottom waters. All three periods show high abundances of 7Me-C_{17} and heterocyst glycolipids (HGs), which are specific biological markers for heterocystous cyanobacteria (Bauersachs et al. 2009), and prominent stable nitrogen isotope excursions to comparatively low $\delta^{15}N$ values of +2‰ that together provide evidence for an increased frequency and intensity of blooms of heterocystous cyanobacteria in the Baltic Sea during the Holocene. Interestingly, times of high cyanobacterial activity are characterized by high TEX^L_{86}-based sea surface temperatures (SSTs) indicating that water temperatures exceeding a threshold of about 15 °C are essential for promoting the formation of cyanobacterial blooms in the Baltic Sea. Our data thus suggests that climate-induced variations in SST largely controlled the formation and extent of cyanobacterial blooms in the Baltic Sea and that once cyanobacterial blooms are established they induces a self-sustaining feedback loop that facilitates and accelerates the spread of bottom water hypoxia in the Baltic Sea. Moreover, our data indicate that cyanobacterial blooms were more prevalent during the HTM and MCA as compared to the MHP. In turn, this suggests that future climate warming will lead to an overall intensification of cyanobacterial blooms and bottom water hypoxia with severe consequences for the ecosystem properties of the Baltic Sea.

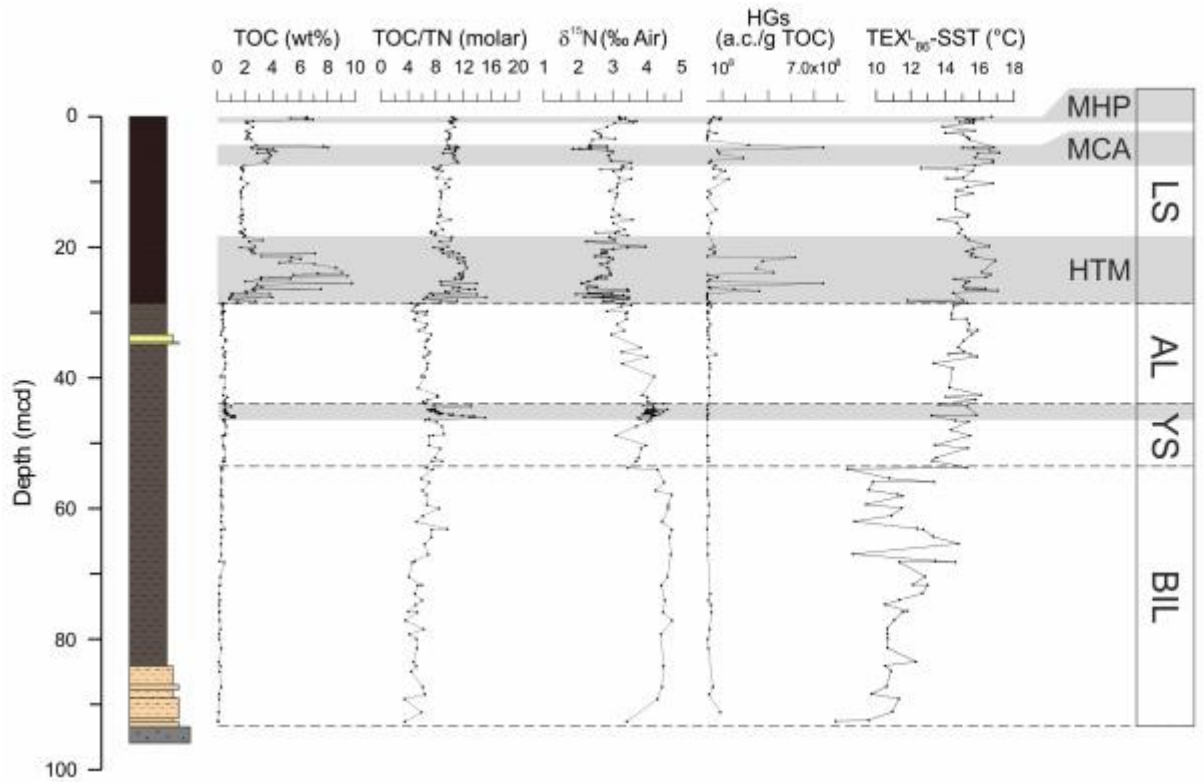

Figure 1. *Downcore profiles of total organic carbon (TOC), molar total organic carbon/total nitrogen (TOC/TN) ratios, stable nitrogen isotopes ($\delta^{15}N$), heterocyst glycolipid (HG) abundances and TEX^{L}_{86}-based surface water temperatures (SST). LS = Littorina Sea; AL = Ancylus Lake; YS = Yoldia Sea; BIL = Baltic Ice Lake; MHP = Modern Hypoxic Period; MCA = Medieval Climate Anomaly; HTM = Holocene Thermal Maximum*

References

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