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Interactive Comment

Interactive comment on "Hypoxia and cyanobacterial blooms are not natural features of the Baltic Sea" *by* L. Zillén and D. J. Conley

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The uncertainties associated with radiocarbon dating of bulk sediment samples are thoroughly discussed in Zillén et al. 2008 as well as the quality of the sediment descriptions of the cores used in that study. There is therefore no need to further discuss these issues in this manuscript. We do make the important statement that improved time control is needed to better constrain the periods of hypoxia in order to disentangle the effects of human and climate forcing on the Baltic Sea ecosystem.

It has been demonstrated that short term trends (< 30 years) in hypoxia during the modern era in the Baltic Sea are related to variations in salt water inflows from Kattegat, with less stratification and less hypoxia during "stagnation periods" (i.e. in the 1920/1930s, 1950/1960s and the 1980/1990s). During these "stagnation periods" the

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Discussion Paper

salt water inflows are reduced and the salinity of the Baltic Sea decreases by about 0.5 salinity units lower than the mean value (Meier & Kauker, 2003). In addition, we know that short-term episodic inflows of salt water from the North Sea affect the overall salinity in the Baltic Proper.

The majority of past salinity reconstructions imply low and relatively stable values from c. 3000 cal. yr BP to the present. Only the estimates by Emeis et al. (2003) show a steady increase in salinity from about 3000 cal. yr BP, although higher salinities during this period are not supported by diatom studies (Andrén et al. 2000a;b) or the reconstruction by Gustafsson and Westman (2002). The salinity estimates used by Leipe et al. (2008) are those presented in Emeis et al., (2003) which are derived from 13C/12C ratio of organic carbon measurements. The sample set used for the δCTOC/salinity transfer function is sparse and consist of no more than nine data points (Emeis et al. 2003). It also suggests a salinity of 4-6 during the freshwater Ancylus Lake Stage, thus demonstrate the large uncertainties associated with this method in absolute paleosalinity reconstructions. In the absence of multiple high-resolution salinity reconstructions, we therefore suggest that hypoxia in the Baltic Proper during the last two millennia does not show a relationship to any known changes in salinity.

There are no geochemical records, such as Mn, Ca-rich laminae, demonstrating that inflows of salt water have increased during the last four millennia. These laminae form when the overlying water column is hypoxic/anoxic and where changes in redox conditions triggers (Mn, Ca)CO3 precipitation. This occurs when sporadic inflows of oxygen rich water reach deep hypoxic waters, where reductive dissolution yields in high concentrations of dissolved Mn, which allow (Mn, Ca)CO3 laminae to form. The formation and preservation of these laminae require almost permanent hypoxia to develop and would therefore not be present in homogenous sediments (e.g. Burk and Kemp, 2004). The presence of Mn-rich lamina in the sediment sequences thus only supports evidence of saltwater inflow during hypoxic periods, not prior or after the periods of hypoxia. Consequently, the lack of Mn-carbonates can only be used as an indicator of

BGD

7, C1316–C1323, 2010

Interactive Comment

oxic conditions, not as absence of salt water inflows. Moreover, the post-glacial sediment sequence studied by Burk and Kemp (2004) is no more than c. 2.2 m long and dated by only one 14C AMS measurement, which show an age of 5050 cal. yrs BP in the lower part. Based on this single date (which seems far too young) it is impossible to say anything about the late Holocene development. Furthermore, Burk and Kemp (2004) performed SEM- analysis at sediment depths between 165-216 cm (i.e. the lower most part of the core), hence just providing a 51 cm long record of potentially saline inflows to the Baltic Sea.

There is extensive evidence that the climate anomaly know as the Medieval Warm Period, MWP (between c. AD 1000 and 1300; Lamb, 1965) was markedly dryer and warmer (c. 0.2-0.4 degrees warmer than today (or relative to the time period 1850-1995; Mann et al, 2008) than the following LIA, especially in summer temperatures of Europe. Dry conditions during the MWP are supported by European dendroclimate precipitation reconstructions (Helama et al., 2009) and tree-line and lake-level reconstructions in the Kola Peninsula, Russia (Kremenetski et al., 2004) where submerge tree-stumps of medieval age indicate severe drought with low lake-levels during this time period followed by wetter conditions. Minimum spring snow-melt discharges in River Ångermanälven (one of the largest rivers in northern Sweden) during the MWP accompanied by significantly increased discharges during the time-span of the LIA have been reconstructed from studies of clastic varves in the Ångermanälven's estuary (Sander, 2003). Furthermore, dry conditions during the MWP have been registered in various European palaeoenvironmental archives including peat deposits in northern Poland (Lamentowicz et al., 2008) and oxygen isotope (δ18O) concentrations in speleothems in Norway (Lauritzen and Lundberg, 1999) and lake sediments in northern Sweden (Hammarlund et al., 2002). Less precipitation in combination with high evaporation rates caused decreased net precipitation (Hammarlund et al., 2003; Jessen et al., 2005; de Jong et al., 2006). Both warmer summers and winters during the MWP has been inferred from lake sedimentary records (Weckström et al., 2006) with possible diminished winter snow-cover in west-central Sweden and southern and eastern Finland (Zillén, 2003; Halta-Hovi et al., 2007). Due to a more northerly position of Polar Front, sea-ice in the North Atlantic region was reduced (Lamb, 1965) and westerly winds at latitudes between c. 50 and 65°N were presumably weaker and less prevalent (de Jong et al., 2006; Aagaard et al., 2007; Clarke & Rendell, 2009).

During the LIA, European mean annual temperatures were c. 0.8. °C colder than today (or relative to 1901-1995; e.g. Mann et al., 2008). Increased sea-ice in the North Atlantic region, including the Greenland Sea, caused increased air pressure near Island and a large southward displacement of the polar front (Lamb, 1965; Clarke & Rendell, 2009). As a result, the Polar Front Jet and the associated cyclone track shifted southward creating an increased thermal gradient between 50° N and 65° N bringing frequent storms to Northwest Europe (Lamb, 1995; Dawson et al., 2002; Clarke & Rendell, 2009). Increased wind velocities in North West Europe are thus associated with two different atmospheric situations i.e. a positive NAO index and a southerly displacement of the Polar Front (the latter probably more important on long time-scales (Dawson et al., 2002). In both two cases, atmospheric pressure contrasts are enhanced and storminess increased (Dawson et al., 2002). Increased storminess with frequent passages of cyclones during the LIA has been reconstructed from sand-drift studies in a variety of places in North West Europe (de Jong et al., 2006; Aagaard et al., 2007; Clarke and Rendell, 2009). Furthermore, relative wet conditions in bogs and lakes in south-west Sweden (Hammarlund et al., 2003; Jessen et al., 2005; de Jong et al., 2006) indicate more wet and moist conditions during this time period caused by increased transport of moist Altantic air by westerly air-flows. Also, as pointed out in the comment by J.W. Dippner, various climate reconstructions of the last 1000 years show an increase in precipitation between c. AD 1240-1800. The hypothesis that increased precipitation during the MWP would have caused increased runoff and nutrient loads is therefore not supported by paleoclimate scenarios. In contrast, it is more likely that increased land-use changes caused such changes.

Hypoxia between c. 2000-800 cal yr BP does overlap with the warmer MWP. However, temperatures have no proven effects on the oxygen conditions in the Baltic Sea and the relationship between primary production and climate change is not linear (Richardson & Schoeman, 2004). The link between phytoplankton abundance and sea surface temperature is only indirectly coupled to temperature. The ecological response to NAO (North Atlantic Oscillation) has been reviewed and several correlations between climate and ecological changes have been verified, although the mechanism behind is not understood (e.g. Ottersen et al. 2001). At the Swedish west coast a strong correlation between phytoplankton biomass and NAO has been found, possibly caused by an increased stratification in Skagerrak (Belgrano et al., 1999). In the North Sea there has been an increase in phytoplankton season length and abundance since the mid 1980's interpreted as a response to climatic forcing (Reid et al., 1998). Although NAO is well known to influence climate conditions in the Baltic Sea during the last c. 100 years, no direct links between NAO, hypoxia and inflow of salt water have been firmly established. Large scale land-use changes and eutrophication in the Baltic Sea watershed (Renberg et al. 2001; Bradshaw et al. 2005) is an equivalent independent potential forcing mechanism on increased productivity and hypoxia, as climate variability.

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