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Changes in chlorophyll concentration and phenology in the North Sea in relation to de-eutrophication and sea surface warming

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At least two major drivers of phytoplankton production have changed in recent decades in the North Sea: sea surface temperature (SST) has increased by ~ 1.6°C between 1988 and 2014, and the nitrogen and phosphorus loads from surrounding rivers have decreased from the mid-1980s onward, following reduction policies. Long time series spanning four decades (1975–2016) of nutrients, chlorophyll (Chl), and pH measurements in the Southern and Central North Sea were analyzed to assess the impact of both the warming and the de-eutrophication trends on Chl. The de-eutrophication process, detectable in the reduction of nutrient river loads to the sea, caused a decrease of nutrient concentrations in coastal waters under riverine influence. A decline in annual mean Chl was observed at 11 out of 18 sampling sites (coastal and offshore) in the period 1988–2016. Also, a shift in Chl phenology was observed around 2000, with spring bloom formation occurring earlier in the year. A long time series of pH in the Southern North Sea showed an increase until the mid-1980s followed by a rapid decrease, suggesting changes in phytoplankton production that would support the observed changes in Chl. Linear correlations, however, did not reveal significant relationships between Chl variability and winter nutrients or SST at the sampling sites. We propose that the observed changes in Chl (annual or seasonal) around 2000 are a response of phytoplankton dynamics to multiple stressors, directly or indirectly influenced by de-eutrophication and climate warming.