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ORIGINAL RESEARCH ARTICLE

Response patterns of phytoplankton growth to variations in resuspension in the German Bight revealed by daily MERIS data in 2003 and 2004☆

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Summary Chlorophyll (chl *a*) concentration in coastal seas exhibits variability on various spatial and temporal scales. Resuspension of particulate matter can somewhat limit algal growth, but can also enhance productivity because of the intrusion of nutrient-rich pore water from sediments or bottom water layers into the whole water column. This study investigates whether characteristic changes in net phytoplankton growth can be directly linked to resuspension events within the German Bight. Satellite-derived chl *a* were used to derive spatial patterns of net rates of chl *a* increase/decrease (NR) in 2003 and 2004. Spatial correlations between NR and mean water column irradiance were analysed. High correlations in space and time were found in most areas of the German Bight ($R^2 > 0.4$), suggesting a tight coupling between light availability and algal growth during spring. These correlations were reduced within a distinct zone in the transition between shallow coastal areas and deeper offshore waters. In summer and autumn, a mismatch was found between phytoplankton blooms (chl $a > 6$ mg m^{-3}) and spring-tidal induced resuspension events as indicated by bottom velocity, suggesting that there is no phytoplankton resuspension during spring tides. It is instead proposed here that frequent and recurrent spring-tidal resuspension events enhance algal growth by supplying remineralized

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nutrients. This hypothesis is corroborated by a lag correlation analysis between resuspension events and in-situ measured nutrient concentrations. This study outlines seasonally different patterns in phytoplankton productivity in response to variations in resuspension, which can serve as a reference for modelling coastal ecosystem dynamics.

1. Introduction

Coastal areas exhibit great variability in physical and biological processes, making it difficult to pinpoint spatio-temporal algal growth distribution patterns. In large part, this variability results from a complex interplay of sediment resuspension, phytoplankton growth, grazing, aggregation, and sinking of particulate matter. Primary factors controlling coastal phytoplankton distribution and growth include surface temperature, turbidity, river nutrient loads, and benthic and pelagic consumers, as well as tidal mixing (Loebl et al., 2009; Malone et al., 1983; Soetaert et al., 1994). These factors interfere with strong horizontal advection (Lucas et al., 1999).

Resuspension is a physical process that occurs when bottom shear stress is high enough to lift sediment particles (Wainright, 1990). Physical causes of resuspension include strong winds and tidal currents. In winter and spring, strong winds generate turbulent mixing. In shallow waters, turbulence not only retains suspended particles in the water column, but also detaches benthic material. Both processes increase the concentration of suspended particulate matter (SPM). SPM in turn negatively affects light availability for phytoplankton growth (Fig. 1, May et al., 2003; Wild-Allen et al., 2002). Wind-induced mixing has indeed been shown to determine effectively the spreading of algal spring blooms in coastal seas (Mei et al., 2010; Tian et al., 2009). In shallow coastal seas, strong tidal mixing also influences phytoplankton growth (Sharples et al., 2006). For instance, weakened mixing during neap tides favours stratification (Simpson et al., 1990). Results from harmonic analysis (von Storch and Zwiers, 2001) of satellite SPM images in the southern North Sea suggest pronounced spring-neap variations, thereby revealing how changes in tidal mixing govern the distribution of SPM (Pietrzak et al., 2011). In summer and autumn, tidal currents cause resuspension of benthic material, which can supply nutrients from sediment layers or bottom water layers to the water column (Fig. 1). These remineralized nutrients originate from the decomposition of organic matter that sank out of the water column and accumulated on the seabed shortly after the spring bloom (Ehrenhauss et al., 2004). Therefore, explaining the origin of bloom events in autumn is difficult because it involves reconciling two conflicting resuspension effects (high turbidity versus nutrient recycling) on phytoplankton growth (Fichez et al., 1992).

To date, the role of resuspension in coastal phytoplankton growth has rarely been addressed on a system scale. Previous studies of the effects of resuspension were based on laboratory work or on local in-situ measurements (Koschinsky et al., 2001; Sloth et al., 1996; Tengberg et al., 2003). Spatial extrapolations of local resuspension effects are limited because resuspension and phytoplankton growth have a strong mesoscale component (Gerritsen et al., 2001; Lou et al., 2000; Stanev et al., 2007). Satellite ocean colour data provide a unique tool for monitoring these effects. However, given spatio-temporal variations in bathymetry, atmospheric forcing, and hydrography, resolving how mixing, nutrient availability, and light availability promote phytoplankton blooms in shallow coastal regions remains a challenging task, especially when compared to simpler open ocean conditions (Lucas et al., 1998).

The German Bight (GB), located in the south-eastern portion of the North Sea, is a shallow area with average water depths of about 22 m (Fig. 2). In such shallow water, wind and tidal waves have an impact on the bottom, and resuspension has an impact on the water column. Our synoptic view of biophysical processes in the GB is gradually improving thanks to continuing in-situ measurements and

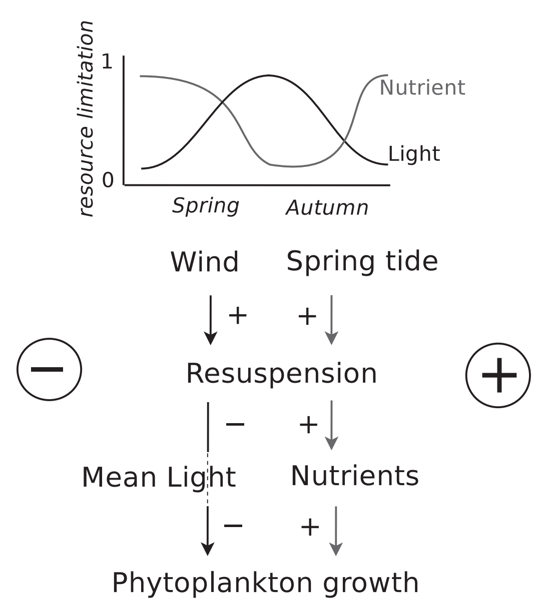

Figure 1 Schematic diagram of how resuspension influences phytoplankton growth. The upper graph generalizes the seasonal variations of the two main limiting factors in the German Bight: light and nutrients. The +/− signs with arrows indicate the positive/negative effects. In spring, phytoplankton reacts negatively to increased resuspension induced by wind. In contrast, in late summer and autumn, recurrent resuspension induced by the spring tide refuels phytoplankton growth with remineralized nutrients.