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Environmental controls on phytoplankton community composition in the Thames plume, U.K.

Keith Weston [a,*], Naomi Greenwood [b], Liam Fernand [b], David J. Pearce [b], David B. Sivyer [b]

[a] Laboratory of Global Marine and Atmospheric Chemistry, School of Environmental Sciences, University of East Anglia, NR4 7TJ, UK
[b] Centre for Environment, Fisheries and Aquaculture Science, Lowestoft, Suffolk NR33 0HT, UK

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ABSTRACT

The aim of this study was to investigate controls on the phytoplankton community composition and biogeochemistry of the estuarine plume zone of the River Thames, U.K. using an instrumented moored buoy for *in situ* measurements and preserved sample collection, and laboratory-based measurements from samples collected at the same site. Instrumentation on the moored buoy enabled high frequency measurements of a suite of environmental variables including *in situ* chlorophyll, water-column integrated irradiance, macronutrients throughout an annual cycle for 2001 *e.g.* nitrate and silicate, and phytoplankton biomass and species composition. The Thames plume region acts as a conduit for fluvial nutrients into the wider southern North Sea with typical winter concentrations of 45 μM nitrate, 17 μM silicate and 2 μM phosphate measured. The spring bloom resulted from water-column integrated irradiance increasing above 60 W h m^{-2} d^{-1} and was initially dominated by a diatom bloom mainly composed of *Nitzschia* sp. and *Odontella sinesis*. The spring bloom then switched after ~30 days to become dominated by the flagellate *Phaeocystis* reaching a maximum chlorophyll concentration of 37.8 μg L^{-1}. During the spring bloom there were high numbers of the heterotrophic dinoflagellates *Gyrodinium spirale* and *Katodinium glaucum* that potentially grazed the phytoplankton bloom. This diatom–flagellate switch was predicted to be due to a combination of further increasing water-column integrated irradiance >100 W h m^{-2} d^{-1} and/or silicate reaching potentially limiting concentrations (<1 μM). Post spring bloom, diatom dominance of the lower continuous summer phytoplankton biomass occurred despite the low silicate concentrations (Av. 0.7 μM from June–August). Summer diatom dominance, generally due to *Guinardia delicatula*, was expected to be as a result of microzooplankton grazing, dominated by the heterotrophic dinoflagellate *Noctiluca scintillans*, controlling 0.7–5.0 μm 'flagellate' fraction of the phytoplankton community with grazing rates up to 178% of 'flagellate' growth rate. The Thames plume region was therefore shown to be an active region of nutrient and phytoplankton processing and transport to the southern North Sea. The use of a combination of moorings and ship-based sampling was essential in understanding the factors influencing nutrient transport, phytoplankton biomass and species composition in this shelf sea plume region.

1. Introduction

Coastal shelf seas, such as the North Sea, are productive marine regions of high societal value and are threatened by multiple pressures including increased nutrient loading and climate change (Jickells, 1998). The North Sea is potentially impacted by anthropogenically increased riverine and atmospheric nitrogen and phosphorus input due to its location, as it is bordered by many of the industrialised nations of northern Europe (Brockmann et al., 1988; Ducrotoy et al., 2000). This anthropogenic derived nutrient input may lead to problems due to hypernutrification such as enhanced primary production leading to low bottom water oxygen levels, *i.e.* eutrophication, and harmful algal blooms with these problems previously identified in the shallow German Bight/Wadden Sea region of the southwestern North Sea (Colijn et al., 2002). The semi-enclosed nature of the North Sea also leads to residence times in the order of weeks for nutrients in southern and central regions (Weston et al., 2004) providing some of the physical and temporal conditions necessary for these problems to develop.

A major physical transport pathway of nutrients in the southern North Sea is the 'East Anglian plume' which converges off the East Anglian coast and in winter transports nutrients from the main English east coast rivers *i.e.*, the Humber, the Wash and the Thames. This nutrient plume is geographically associated with a turbidity plume with the latter frequently detectable in satellite images (van Raaphorst et al., 1998). The transport of water and

* Corresponding author.
E-mail address: k.weston@uea.ac.uk (K. Weston).

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dissolved nutrients, when the plumes are present, is in an anticlockwise direction towards the coastal waters of continental Europe, and in particular the Netherlands, with the potential to transport nutrients, organic matter and pollutants across international maritime boundaries. The River Thames has historically been severely impacted by anthropogenic nutrient inputs leading to low bottom water oxygen concentrations (Wood, 1982). The health of the Thames estuary has however dramatically improved since the 1940s when the Thames estuary was anaerobic year round, with an oxygen depleted zone ~40 km long in 1949 (Tinsley, 1998). The Thames still provides a significant total N input (as nitrate, nitrite and ammonium) to the North Sea of ~39 ktonnes y^{-1} (Nedwell et al., 2002) and is a major UK river with a catchment area of 11,300 km^2. This input is characterised by high concentrations of ammonium up to 24% of total N species due to upstream sewage works (Nedwell et al., 2002) with this sewage input responsible for a localised decrease in dissolved oxygen close to these sewage treatment plants (Kinniburgh, 1998) ~70 km upstream of the Thames plume. This bioavailable N input due to the River Thames into the North Sea is however low relative to the Rhine which is the major riverine N source to the North Sea with dissolved N inputs of ~300 ktonnes y^{-1} (de Jonge et al., 1996).

In order for this N input to reach the North Sea it first passes through the shallow, turbid and well-mixed Thames estuary. This estuary, similar to other shallow estuaries, is a region of low light penetration due to high suspended particulate matter (SPM). This causes light limitation of phytoplankton growth load when SPM concentration is >50 mg L^{-1} (Cloern, 1987; Shaw et al., 1998) and results in restricted uptake of nutrients by phytoplankton and therefore significant transport through this region. The riverine input then enters the Thames plume zone, which links the estuary to the North Sea. In this zone, which is the focus of this study, the SPM decreases to <50 mg L^{-1} (Sanders et al., 2001) and provides a suitable light climate for a diatom spring bloom to develop and hence nutrient uptake into particulate organic matter. The Thames plume zone has high concentrations of nitrate and phosphate throughout the year with concurrently low silicate levels of ~1 μM (Sanders et al., 2001). Under these low silicate to nitrogen and phosphate conditions large scale blooms of the nuisance phytoplankton *Phaeocystis* sp. have been shown to occur in continental coastal regions of the German Bight in the southern North Sea (Lancelot et al., 1987) but blooms of this nuisance flagellate have not recently been recorded in the Thames plume zone. The aim of this study was therefore to investigate the controls on the phytoplankton community structure in the Thames plume and associated biogeochemical parameters using high frequency preserved sample measurements from a moored buoy and, in addition, use samples collected in the plume for laboratory-based nutrient manipulation experiments and microzooplankton grazing measurements. The moored buoy forms a key component of the United Kingdom's National Marine Monitoring Programme (NMMP). The NMMP began in the late 1980s with the aim to detect long-term trends in the quality of the marine environment of the United Kingdom, with real time data from all NMMP mooring stations available from the Cefas website at http://www.cefas.co.uk. These moorings specifically provide the multidisciplinary data necessary to meet international marine monitoring requirements such as the Oslo and Paris Commission (OSPAR) and provide data for assessments applicable to several European Community directives including the Water Framework Directive (2000/60/EC), Urban Waste Water Treatment Directive (91/271/EEC) and Nitrates Directive (91/676/EEC). The data from moorings at all NMMP sites more broadly aims to "detect long term trends in physical, biological and chemical variables" (Anon., 2004) as a part of the European Union's governments efforts to conserve the marine environment.

2. Materials and methods

2.1. Study area

The plume zone begins at mouth of the Thames estuary in the south east of England with a depth of 15 m at the study site (Station A; 51° 31.05′ N 1° 1.90′ E; Fig. 1). This region is well-mixed year round due to shallow water depth and high tidal energy resulting in a homogenous water column. Nutrient input is dominated by the River Thames. The Thames plume then merges into the East Anglian Plume with the latter also transporting fluvial nutrients from the Humber and the Wash across the southern North Sea.

2.2. Sampling methods

An instrumented buoy was moored at station A throughout 2001 and directly measured salinity, optical backscatter (OBS), photosynthetically active radiation (PAR), fluorescence and dissolved nitrate using *in situ* instrumentation. In addition, the buoy also collected discrete preserved samples at 1 m for later nutrient analysis and phytoplankton species determination. Surface water samples were also collected approximately monthly from RV Corystes for nutrients and size fractionated chlorophyll and enabled quality assessment of moored buoy measurements. Bulk discrete samples were collected for laboratory experiments in June (Day number 172), July (201), August (242) and November (334) with day 0 January 1st 2001. Samples taken at the surface were representative of the whole water column due to the well-mixed water column.

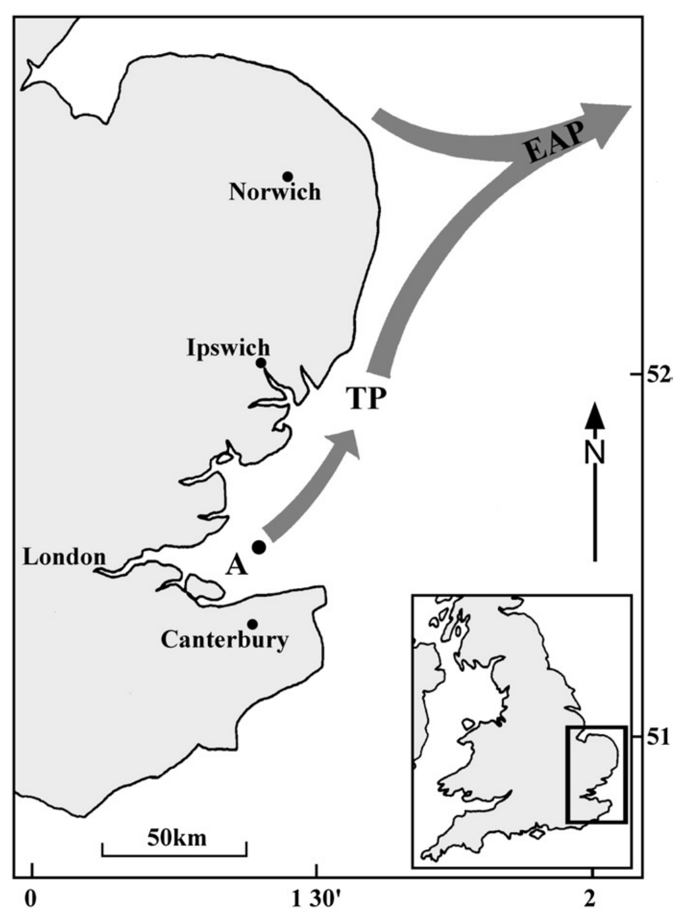

Fig. 1. Map of southwestern North Sea showing location of the sampling station A (also location of moored buoy) and the approximate flow pathways of the Thames plume (TP) and East Anglian plume (EAP).