TRANSPORT AND FATE OF UK NUTRIENT INPUT TO THE SOUTHERN NORTH SEA

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CEFAS
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Introduction

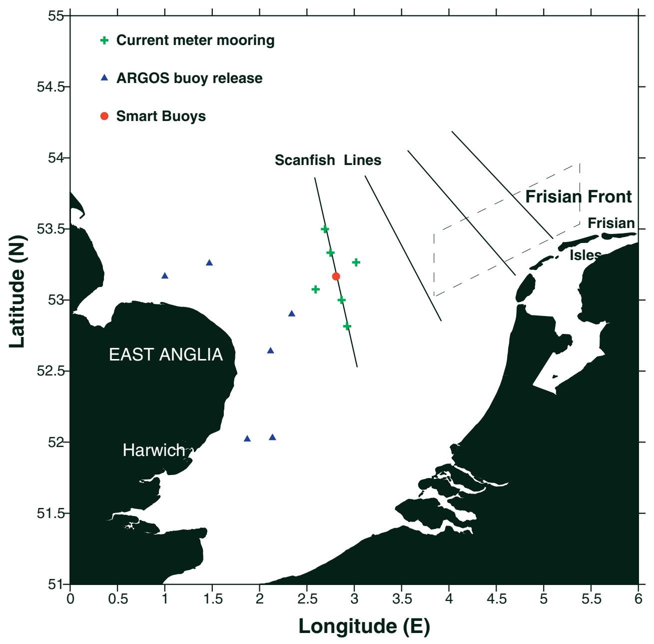

Figure 1.

There is concern that nutrients discharged to the North Sea have an adverse impact on the health of the ecosystem. Much of the nutrient load enters the regional circulation through estuaries, but there is sufficient uncertainty about subsequent transport pathways to allow a clear consensus to develop about the fate of any particular input. For example, recent reports (Baars, 1998) concerning an area of high phytoplankton productivity at the Frisian Front (the 'green curtain') suggest that growth is fuelled directly by nutrients from the UK sector of the North Sea (See Figure 1). It is proposed that low light levels associated with turbid UK coastal waters inhibit utilisation of the nutrient load. As water moves east with the mean circulation, nutrients become directly available to support phytoplankton growth once sediment settles in the lower tidal energy environment to the north of Holland.

Although this conceptual model is plausible, too little is known about flows in the 'plume' area off East Anglia to determine whether this represents water travelling directly to the Frisian Front. There have been few attempts to measure the flow, it's seasonal variability and the influence of seasonal stratification. In addition, the factors (light, turbidity, nutrient ratios) that contribute to the expression of algal growth in these turbid waters are not well understood.

The UK Ministry of Agriculture, Fisheries and Food has commissioned CEFAS and UEA (and in collaboration with NIOZ) to address the uncertainties regarding transport and fate of nutrients in the southern North Sea. An integrated programme of surveys and experimental work has been implemented. This includes measurements made using Smart Buoy, Minipod (bed shear stress and sediment pickup) and current meter moorings (see Figure 1 for positions) together with research vessel surveys using a towed undulating CTD (Scanfish) to gather detailed spatial and temporal information about water, sediment and nutrient transport and the development of phytoplankton. Data from the first field survey and a preliminary assessment is presented here.

Transport

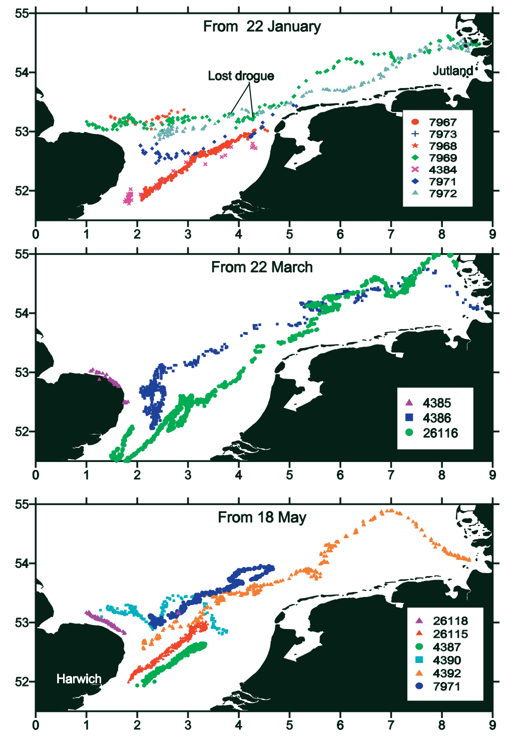

Figure 2.

Satellite tracked drifting buoys with 'holey sock' drogues 5.5 m long and 1.5 diameter and centred at either 8 or 15 m, depending on water depth, were deployed on three cruises (19 - 26 January, 24 - 30 March and 18 - 25 May). Start positions were the same for each deployment (Figure 2). The January/February drifters exhibited a mean eastwards transport of ~ 8 cm s^{-1}, associated with south westerly winds. Those drifters that lost their drogues (7969 & 7972) moved rapidly eastwards at 40 cm s^{-1}, stranding on the Jutland peninsular. The March deployment demonstrated significant differences in flow pattern, initially moving south, then almost due north before moving eastwards in a similar manner to the previous deployment. The May tracks were similar to those in January/February. Drifters off Harwich were driven north-east while those to the north east of Norfolk travelled eastward. The convergence of the tracks through a zone north of the Frisian Islands is the most consistent feature.

24 hourly averages of the residual flow speed and direction (tide removed) measured by a 300 kHz Workhorse ADCP at the centre of the moorings are shown in Figure 3. The mean residual flow for the 109 days was 5.8 cm s^{-1} at 47° relative to true north, within which were comparatively short periods of variability corresponding to changes in wind forcing.

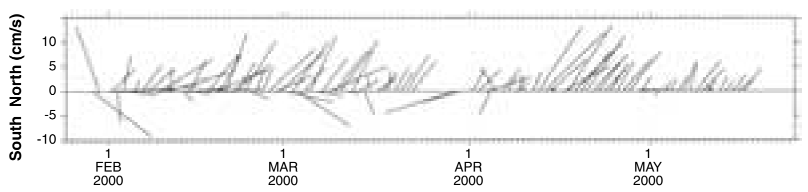

Figure 3. Time series of filtered currents
Lat 53 19.9N, Long 2 45.0E, sounding 33.0 metres, Height 16.0 metres
Observation period = 1150 29 January 2000 to 1150 16 May 2000.

Nutrients and chlorophyll

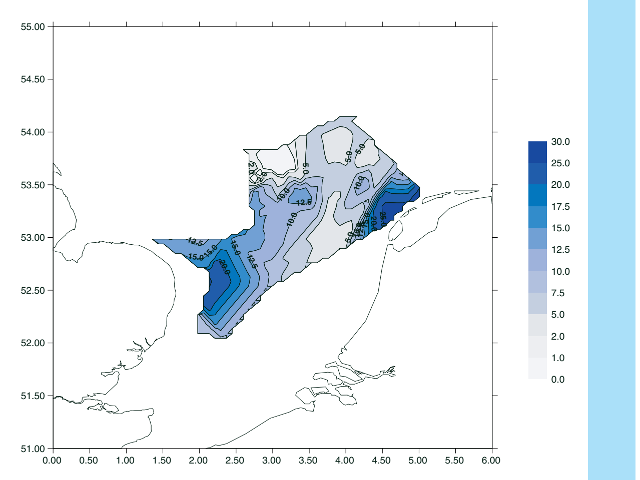

Figure 4a. Spatial distribution of TOxN concentration (µmol/l) in March.

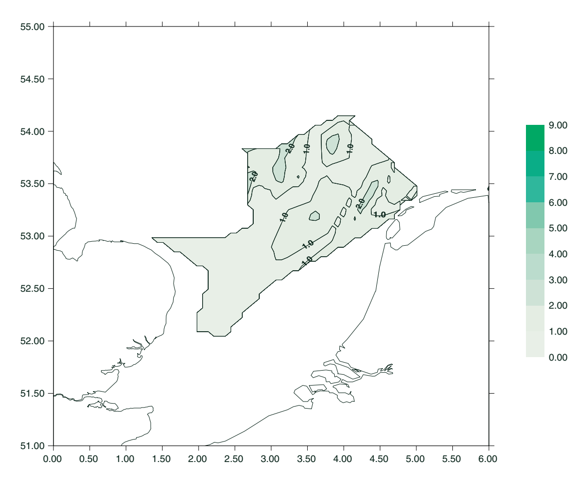

Figure 4b. Spatial distribution of chlorophyll concentration (µg/l) in March.

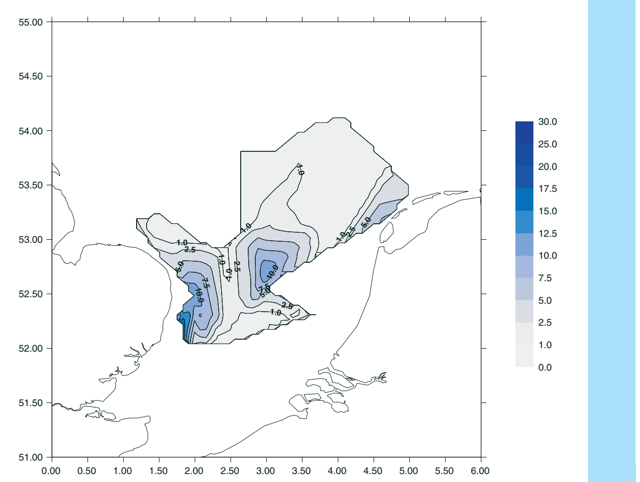

Figure 4c. Spatial distribution of TOxN concentration (µmol/l) in May.

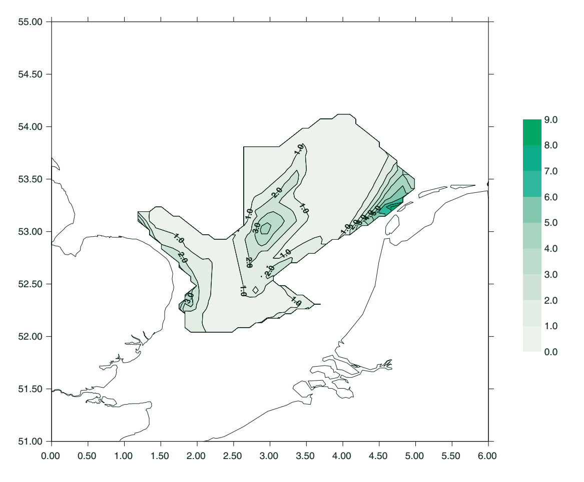

Figure 4d. Spatial distribution of chlorophyll concentration (µg/l) in May.

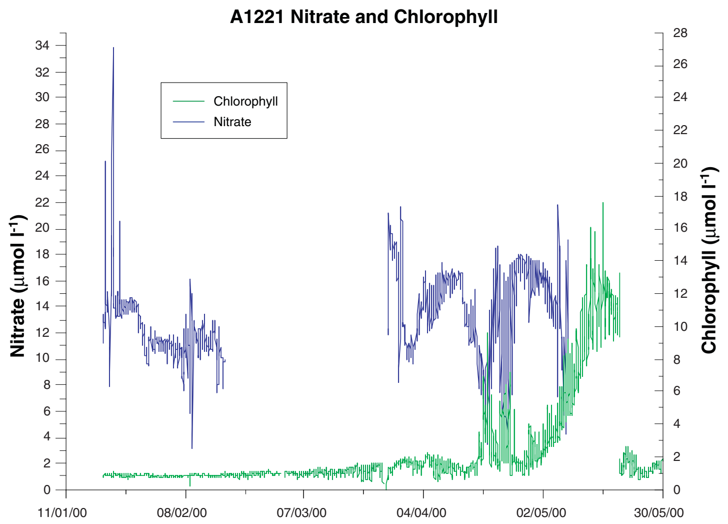

Figure 5. Smartbuoy Trace A1221 Mooring.

Figures 4 a to d show surface spatial distributions of TOxN (Total Oxidised Nitrogen) and chlorophyll during the March and May surveys. Timeseries (January to June) of TOxN and chlorophyll fluorescence from the Smart Buoy at the centre of the mooring array are shown in Figure 5. The high temporal resolution clearly resolves the tidal advection of water with contrasting TOxN/chlorophyll signals. Discrepencies between chlorophyll concentrations around 16th May (Figure 5) implies biofouling of the fluorometer. However, the increase in chlorophyll concentration towards the end of April/early May and associated decrease in nitrate concentration is credible and suggests the onset of the spring bloom. This is reiterated by the spatial plots which indicate pre (March) and post (May) bloom conditions in the survey areas. TOxN is higher (up to 25 µmol l^{-1}) in March than May (up to 12.5 µmol l^{-1}), whilst chlorophyll concentrations were lower (<2 µg l^{-1}) in March with increased chlorophyll biomass (1-5 µg l^{-1}) in May. The patchiness of high/low TOxN and chlorophyll seen in May is likely to be produced by changes/heterogeneity in the light regime and availability of nutrient after the spring bloom. This hypothesis may help explain the occurrence of the chlorophyll maximum (~ 3µg l^{-1}) northwards of the TOxN maximum (~10 µmol l^{-1}) in a region of high TOxN gradients. The anomalous region of high TOxN post bloom indicates an area where TOxN utilisation is prevented for some other reason e.g. suspended load impact on light availability. This control effect is discussed later.

Western Scanfish transects

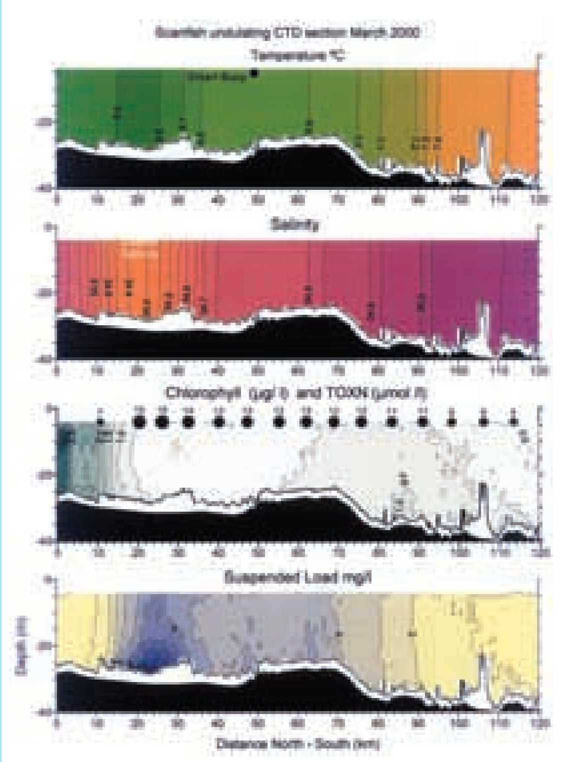

Figure 6a. Scanfish section, March 2000.

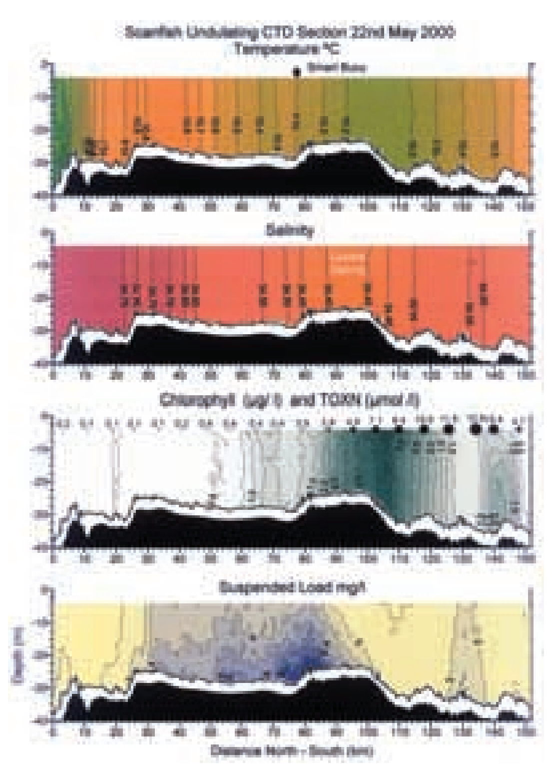

Figure 6b. Scanfish section, May 2000.

Scanfish sections (along the mooring line) of temperature, salinity, chlorophyll (from a calibrated fluorometer) and suspended load (from an optical backscatter device) for March and May are shown in Figures 6a and 6b, respectively. Concurrent surface values of TOxN are plotted on the chlorophyll sections.

In March, warm saline water originating from the English Channel was seen at the south of the transect. Lower salinity and colder water with greater levels of TOxN (maximum 15 µmol l^{-1}) toward the northern end of the transect comes from the English coast. A region of high suspended load (>4 mg l^{-1}) was found between 15 and 70 km along the transect, with highest values occurring near bed at around 25 km. Chlorophyll was uniformly low (<1 µg l^{-1}) in the southern portion of the transect, with a sharp gradient (up to 8.5 µg l^{-1}) in the northern 10 km.

During May (Figure 6b) the lowest salinity water was again associated with low temperatures, but occurred further south and no longer had the highest nutrient values. As before, a zone of elevated suspended load (>4 mg l^{-1}) occurred in the central shallower region of the transect. Highest chlorophyll coincided with strong horizontal nutrient gradients at the southern edge of the turbid region. Low values of TOxN in the north suggest earlier uptake by phytoplankton.

Overall, in March chlorophyll was low with high TOxN, indicating pre-spring bloom conditions. However, in the north the lower suspended load and shallower conditions apparently imply a light regime favourable for growth. This accords with the previously discussed surface contour plots (Figure 4a). Comparison of surface TOxN contour plots in March (Figure 4a) and May (Figure 4c) show evidence of uptake indicative of the initiation of the spring bloom. Data from May (Figure 6b) illustrate this, where surface TOxN were limiting for phytoplankton in the north (up to 90 km along the section) and were associated with low chlorophyll concentrations. Highest concentrations of TOxN are recorded at the southern end of the transect (Figure 6b) together with generally higher chlorophyll. Further evidence that the light regime is favourable for growth in early May is shown in a time series

Conclusions:

Initial results demonstrate the long-term (3 monthly) eastward transport from the UK coastal region passes northward of the region of continental coastal water in the vicinity of the Frisian Front. Variability in wind forcing causes significant changes in transport direction on short (<1 week) time scales. Transport of UK derived nutrients is attenuated/modified by significant production and nutrient utilisation during and following the spring bloom in April/May. There is clear evidence that the suspended load and light regime act as a control on this production.

The timing of the spring bloom is generally regarded as dependent upon the sub-surface light regime. As the water column in the study area is generally vertically well mixed with respect to density then water clarity and the depth determine the light regime for phytoplankton. Consequently, changes in depth or suspended load concentration will play a significant role in determining the timing of the bloom. So variability in the chlorophyll and TOxN concentration within study area and during the study period will largely be a reflection of the optical conditions within the water column. Earlier work in the NERC North Sea programme (Mills *et al.*, 1994) has demonstrated that where suspended inorganic particle load dominates the particle field then it is the primary determinant of the vertical attenuation coefficient for the Southern Bight of the North Sea.

So far, this programme has confirmed the linkages between light regime, production and nutrient utilisation. The impacts of the timing of the spring bloom in UK waters on nutrient/carbon transport to the Frisian Front has yet to be clarified. The influence of light / turbidity regimes (spatially and temporally) on phytoplankton growth in southern North Sea, nutrient and carbon speciation and recycling are questions that remain to be addressed as does the relative contributions of continental and UK waters to production in the Southern Bight. Improved understanding of these issues will be pursued in the latter stages of this project through additional survey work and the development and use of a variety of transport and ecosystem models.

Acknowledgements:

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References:

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Mills, D.K., Tett, P.B. and G. Novarino (1994) The spring bloom in the south western North Sea in 1989. Netherlands Journal of Sea Research 33 (1): 65-80.

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