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

by L. Fernand[1], R. Parker[1], K. Weston[2], J. Brown[1], S. Malcolm[1], D. Pearce[1], D. Mills[1] , K. Medler[1] and D. Sivyer[1]

Introduction

Nutrients discharged from land to the North Sea can have an adverse impact on the quality of the ecosystem. Much of the anthropogenic nutrient load enters the sea through estuaries, but despite a general understanding of the regional circulation there is a lack of consensus about the transport pathway and fate of nutrients from any particular input. For example, Baars (1998) suggests that phytoplankton growth at the Frisian Front in the eastern North Sea is fuelled directly by nutrients from the western side of the North Sea. The hypothesis is that phytoplankton growth may be inhibited by low light levels associated with turbid coastal waters (Figure 1) but as water, and associated nutrients, moves east with the mean circulation, phytoplankton can grow utilising the nutrients when the light climate improves due to reduced turbidity in the low tidal energy environment to the north of Holland.

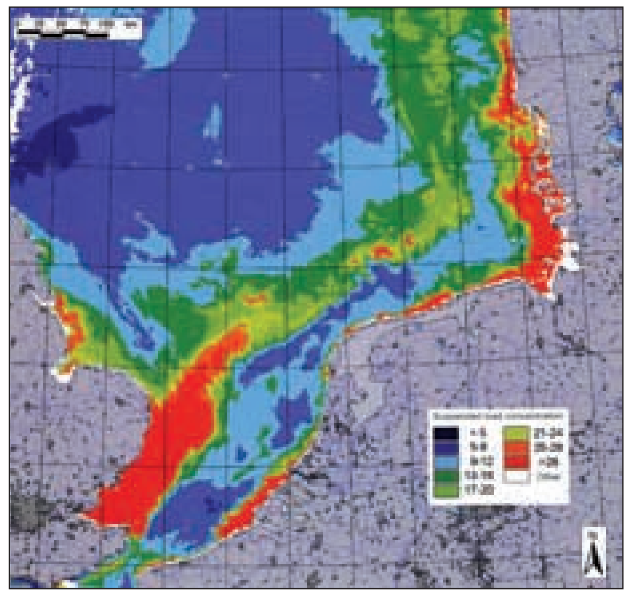
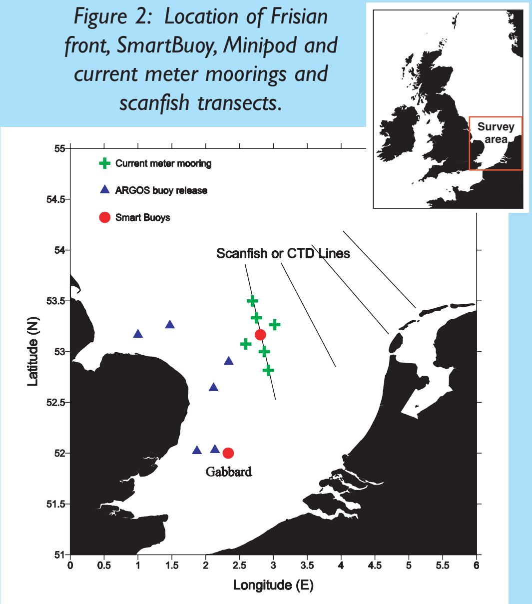


Figure 1: Seawifs satellite image of total suspended load, April 1999 (Hoogenboom 2001)

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 either the flow, it's seasonal variability or 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. This study is designed 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 (for autonomous measurement of water quality parameters), Minipod (bed shear stress and sediment pickup) and current meter moorings (see Figure 2 for positions) together with research 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.

Figure 2: Location of Frisian front, SmartBuoy, Minipod and current meter moorings and scanfish transects.



Transport

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). Figure 3a shows the track for May. Drifters consistently moved eastwards, carried by the tidal residual and weak westerly winds. Similar trajectories were demonstrated at other times, with an increased variability due to wind forcing in the winter months. Figure 3b shows the compilation of all the tracks indicating the clear north eastward transport.

ADCP and conventional current meters give the residual current across the plume in Figure 4. There is little difference in the net transport rate between the seasons (4.5- 7.5 cms^{-1} for winter and 3 - 7 cms^{-1} for summer) however, the variability which is principally due to wind, is 100% greater in winter than summer. The ADCP which profiles through out the water column indicates vertical homogeneity of the response in current speed and direction to forcing.

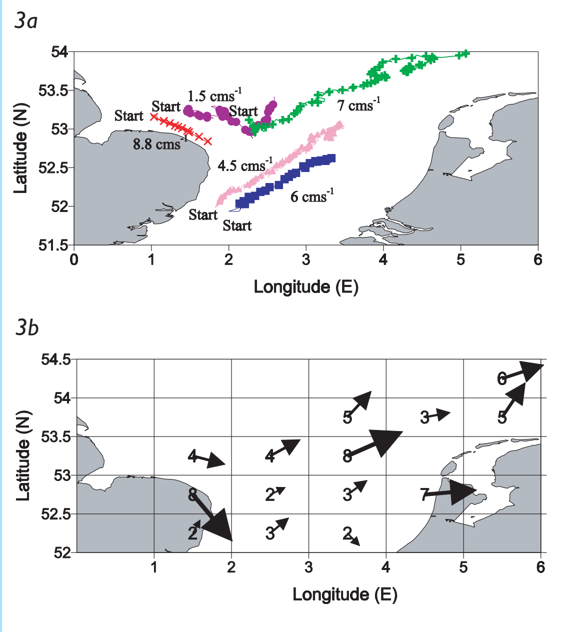


Figure 3a: Argos drifter trajectories May 2000
Figure 3b: The direction and magnitude (cms^{-1}) of net transport: composite of 19 drogued drifters deployed January - June 2000

The record for the central mooring is shown in Figure 5. The mean residual flow for the 109 days was 5.8 cm s^{-1} at 47° relative to true north but there were also comparatively short periods of variability corresponding to changes in wind forcing.

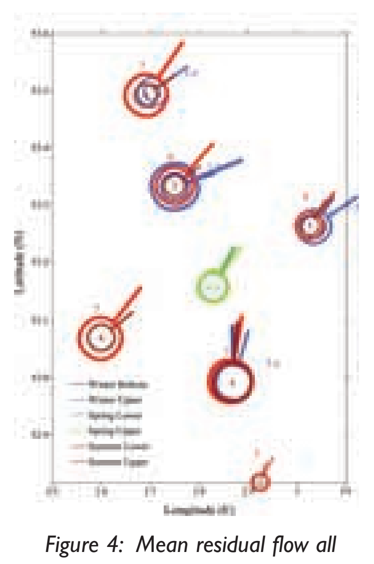


Figure 4: Mean residual flow all deployments 2000

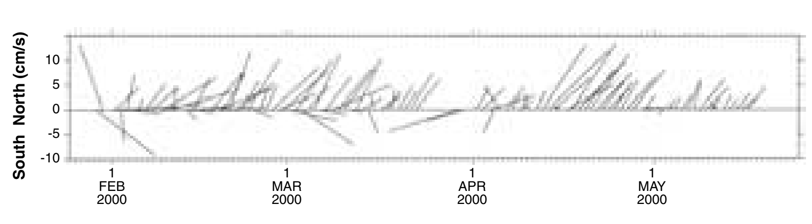


Figure 5. Time series of filtered currents
Lat 53 19.9N, Long 2 45.0E, sounding 33.0 metres, Height 16.0 metres
Observation period = 1150 29 January 2000 to 1150 16 May 2000.

Nutrients and chlorophyll

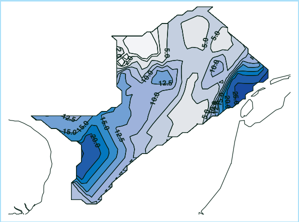


Figure 6a: Spatial distribution of TOxN concentration (μmol/l) in March 2000

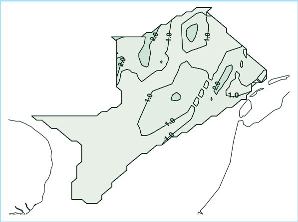


Figure 6b: Spatial distribution of chlorophyll concentration (μg/l) in March 2000

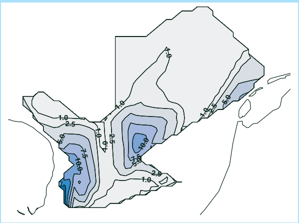


Figure 6c: Spatial distribution of TOxN concentration (μmol/l) in May 2000

Figure 6d: Spatial distribution of chlorophyll concentration (μg/l) in May 2000

Figures 6 a to d show surface spatial distributions of TOxN (Total Oxidised Nitrogen) and chlorophyll during the March and May surveys. Timeseries (January to September) of TOxN and chlorophyll fluorescence from the Smart Buoy at the centre of the mooring array and another site further inshore (Gabbard) are shown in Figure 7. The high temporal resolution clearly resolves the tidal advection of water with contrasting TOxN/chlorophyll signals.

The increase in chlorophyll concentration towards the end of April/early May at both sites and associated decrease in nitrate concentration is the onset of the spring bloom. The same change is seen in 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. poor light conditions due to increased suspended load. TOxN concentrations at both mooring sites remain very low after the spring bloom but recover towards July/August although still at low levels (<2-5μmol/l).

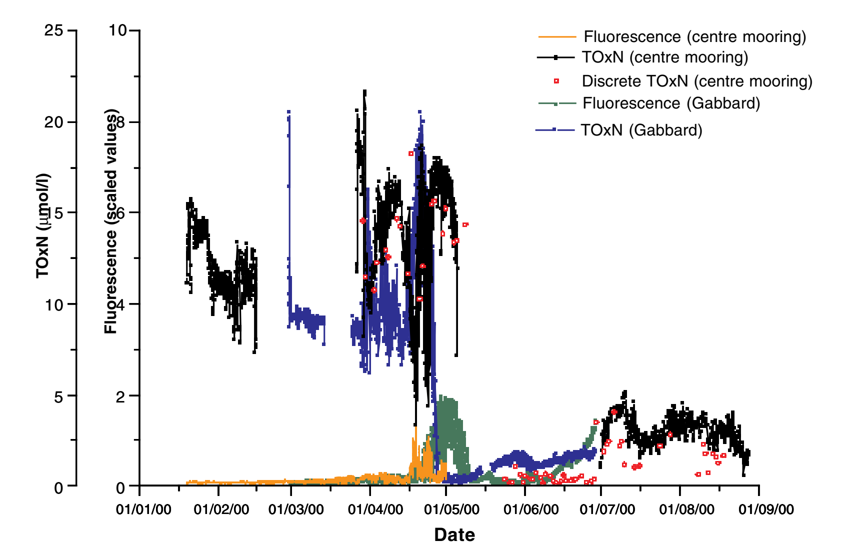


Figure 7: Timeseries of TOxN and fluorescence froms SmartBuoys at centre of the mooring array and Gabbard (January to September 2000)

Preliminary results of work on ^{15}N uptake rates and nitrate and ammonium turnover times in a west to east transect across the Southern North sea through the mooring line (May and July) found that nitrogen utilisation at this time is dominated by ammonium uptake rather than nitrate uptake (Figure 8). This pattern is reflected in the turnover time with highest average value for ammonium turnover during July '00 (Figure 9). If the turnover time = 1.0 the total pool will taken up in 1 day. These high ammonium turnover rates coupled with the inhibitory effects of ammonium on nitrate uptake may limit the rate of nitrate depletion in nutrient-rich, grazing balanced ecosystems such as the southern North Sea (Wheeler and Kokkinakis, 1990) and may have a significant impact on total nitrate transport across the southern North sea post spring bloom. The ammonium in the southern North Sea however is not solely due to zooplankton grazing and bacterial remineralisation of organic matter ('regenerated'), as atmospheric input of ammonium supports up to ~6% of the total 'new' production (de Leeuw *et al.* 2001).

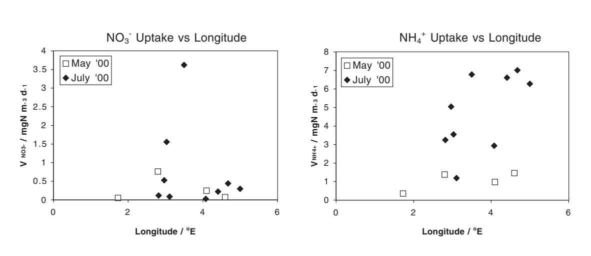


Figure 8: 15^N uptake rates for southern North Sea (Values are average of uptake at 75%, 50% and 25% ambient light level)

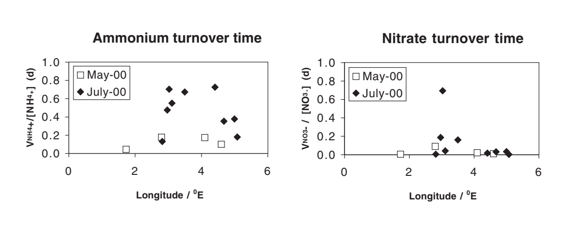


Figure 9: Nitrate and ammonium turnover times

Acknowledgements:

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References:

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de Leeuw et al., (2001) Atmospheric Nitrogen Inputs into the Coatal Ecosystem (ANICE). Final report to EU of ANICE project October 2001

Wheeler, P.A. and S.A. Kokkinakis. 1990. Ammonium limits nitrate use in the oceanic subarctic Pacific. Limnol. Oceangr. 35:1267-1278

Western Scanfish transects

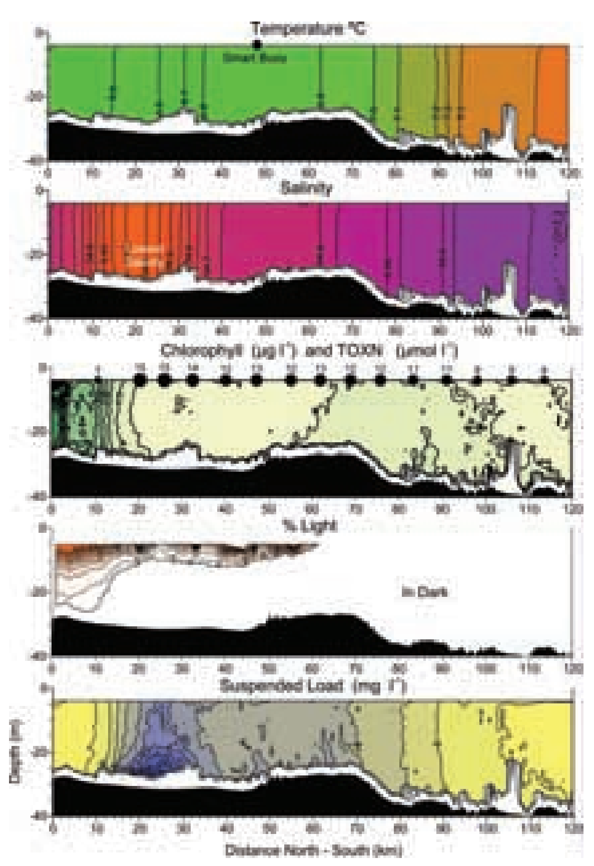

Figure 10a. Scanfish section, March 2000.

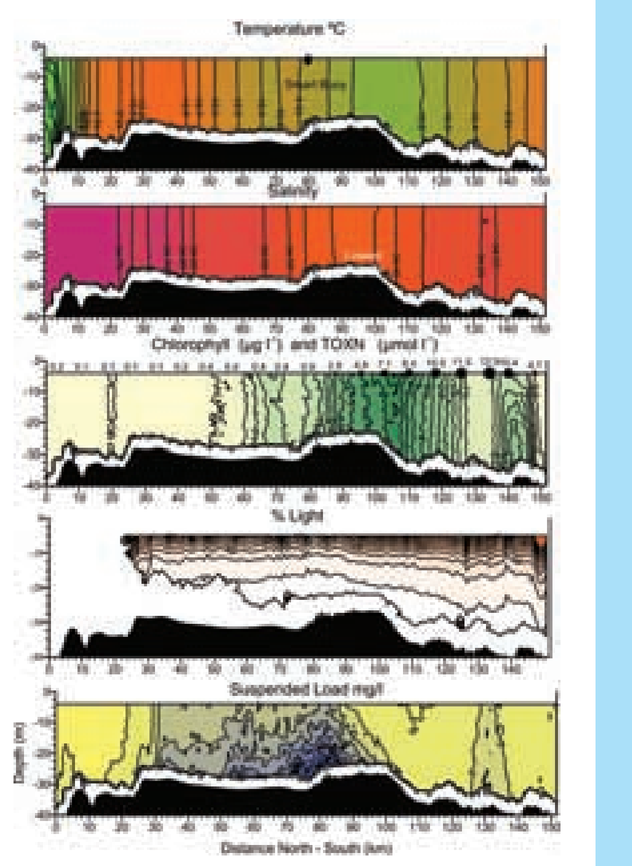

Figure 10b. Scanfish section, May 2000.

Scanfish sections (along the mooring line) of temperature, salinity, chlorophyll (from a calibrated fluorometer), light and suspended load (from an optical backscatter device) for March and May are shown in Figures 10a and 10b, 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 10b) 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, but as shown by the % light plot this has no discernable impact on the water column light regime. 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 surface contour plots (Figure 6a and 6b). Comparison of surface TOxN contour plots in March (Figure 6a) and May (Figure 6c) show evidence of uptake indicative of the initiation of the spring bloom. Data from May (Figure 10b) illustrate this, where surface TOxN concentrations 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 10b) together with generally higher chlorophyll.

Conclusions:

The long-term 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 in winter 75% of residual flow is eastward, 25% westward. In summer the flow is eastward > 90% typically around 5 cm s^{-1}.

It is clear that nitrogen species (NO_3 and NH_4)and/or carbon can be transported by this residual flow from the west to east. However, does this flux of N and C lead to changes in phytoplankton growth?

This study has demonstrated that the turbid water (plume) does not inhibit production and nutrient utilisation does occur in the region east of the UK coast. However, there is clear evidence that the suspended load and light regime act as a control on production as can be seen from the patchy nature of the TOxN/chlorophyll spatial plots. 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 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 and hence the overall nutrient transport against seasonal inputs.

This programme has confirmed the linkages between light regime, production and nutrient utilisation. The impact of the timing of the spring bloom in UK waters and significance of ammonium turnover and nitrate uptake inhibition on nutrient/carbon transport to the Frisian Front has yet to be fully 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 areas of the Southern Bight. Improved understanding of these issues and their effect on the transport and fate of nutrients will enable better management of nutrient discharges for the North Sea ecosystem.

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[1] The Centre for Environment, Fisheries and Aquaculture Science (CEFAS), Lowestoft Laboratory, Pakefield Road, Lowestoft, Suffolk, NR33 0HT, UK

[2] School of Environmental Sciences, University of East Anglia, Norwich, NR4 7TJ, UK

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