The use of high-frequency observations in the calculation of primary production

National Oceanography Centre, Southampton
University of Southampton and Natural Environment Research Council
A. K. Dennis* and D. A. Purdie
School of Ocean and Earth Science, National Oceanography Centre, Southampton www.noc.soton.ac.uk

Cefas
R. M. Forster, N. Greenwood and D. K. Mills
Centre for Environment, Fisheries & Aquaculture Science, Lowestoft www.cefas.co.uk

Background

The waters around the UK are shallow, dynamic environments, and events such as phytoplankton blooms occur over a wide range of spatial and temporal scales. Most investigations of blooms have been conducted with ship surveys and discrete water samples. The spatial resolution can be assessed but much of the progression and variability of a bloom event may be missed as a result of low temporal resolution. Furthermore, winter pre-curser data may be missing as surveys are hampered by poor winter weather. Estimates of primary production and nutrient uptake are consequently limited. High-frequency time-series of mooring data can be used to record transient events and calculate biological rates.

Figure 1: Past (blue) and present (red) locations of SmartBuoys

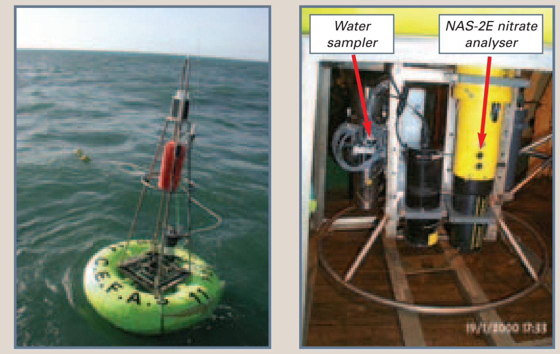

Figure 2: A SmartBuoy in location and a view of its sub-surface instrumentation

SmartBuoy

SmartBuoy is a moored data buoy system that collects near-surface measurements at high frequency for extended periods, thus providing the quantity of data and temporal resolution needed to fully investigate bloom dynamics. There are currently 4 SmartBuoys deployed in UK coastal waters (Figure 1). Near real-time data are published on the internet (www.cefas.co.uk/monitoring) and logged data are retrieved during buoy servicing. Lab calibrations are applied to data to derive variables such as chlorophyll biomass and suspended load (Table 1).

Table 1: Details of the SmartBuoy instruments, variables measured, and possible derived variables

Instrument/Sensor	Variable	Derived variable
Multi-channel logger and system controller with telemetry, interfaced with various sensors	Salinity Temperature Chlorophyll fluorescence Turbidity PAR irradiance at 1m and 2m	Attenuation coefficient, K_d Chlorophyll biomass Surface irradiance
Aqua Monitor water sampler	Samples collected, preserved and stored for subsequent lab analyses	TOxN (total oxidised nitrogen) Dissolved silicate Suspended load Phytoplankton counts and composition
NAS-2E and NAS-3X *in-situ* nitrate analyser	TOxN (total oxidised nitrogen)	Nutrient uptake rates

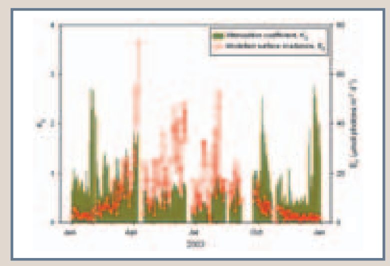

Figure 3: Mean daily attenuation coefficient and modelled daily surface irradiance (Liverpool Bay, 2003)

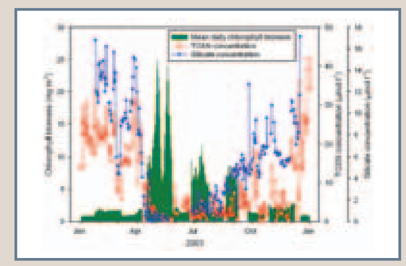

Figure 4: Mean daily chlorophyll biomass, TOxN concentration and silicate concentration (Liverpool Bay, 2003)

Data

Using the PAR readings at 1m and 2m it is possible to calculate the attenuation coefficient (K_d) and from this the euphotic depth and the surface irradiance (Figure 3). The mean daily euphotic depth (Z_{eu}), daily surface irradiance (E_o) and mean daily chlorophyll biomass (B – see Figure 4) were combined into a composite parameter in the equation of Cole and Cloern (1987) and used to estimate daily primary production. Where data were missing production values were extrapolated; it was then possible to sum daily production to estimate monthly (Figure 5) and annual carbon production (Figure 6). Across all sites, annual production estimates range from 72 to 240 g C m^{-2}. In Liverpool Bay estimates range from 124 to 182 g C m^{-2}; this compares well with a value of 182 g C m^{-2} estimated from 9 cruises in the Irish Sea during March-October 1997 (Gowen *et al.*, 2000). The high frequency chlorophyll and nutrient data demonstrate the effect of a large bloom on nutrient concentrations (Figure 4), and such data allow the calculation of nutrient uptake rates and hence C:N ratios (Figure 7).

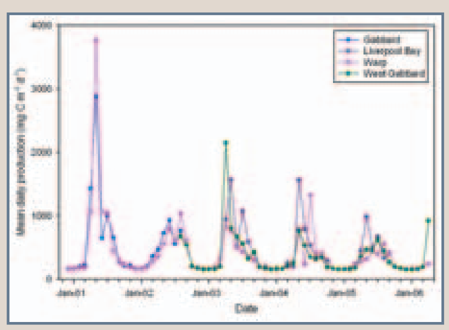

Figure 5: Mean daily production estimated from calculated and extrapolated values

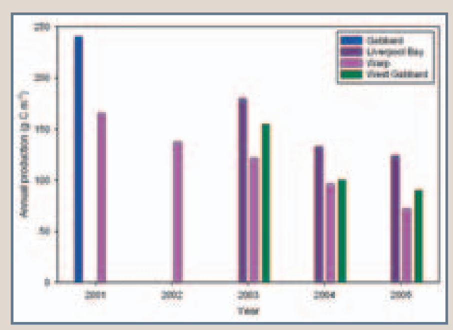

Figure 6: Annual primary production estimated from calculated and extrapolated values

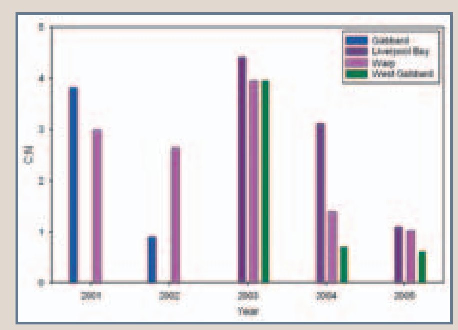

Figure 7: C:N ratios for the spring bloom period at each buoy

Checking the production model

A biomass-irradiance-euphotic depth ($B.E_o.Z_{eu}$) model was used to estimate depth-integrated daily production at 89 geographically diverse regions as per Campbell *et al.* (2002). The results were compared to production estimates derived from ^{14}C uptake data (Figure 8). When compared to the algorithms tested by Campbell *et al.*, the model was one of the best performing equations with most production estimates falling within a factor of 2 of the ^{14}C data. In addition, the model inputs ($B.E_o.Z_{eu}$) are amenable to measurement via satellite remote sensing, and hence could be used to map primary production at the regional scale.

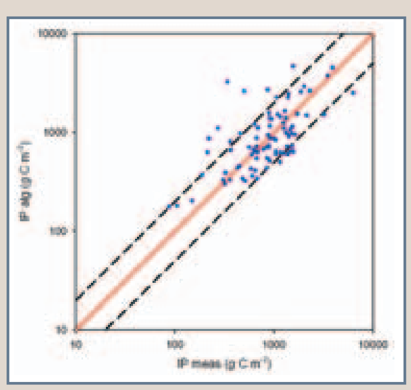

Figure 8: Measured primary production plotted against primary production estimated using data on chlorophyll, euphotic depth and surface irradiance in the model of Cole & Cloern

Conclusions

The SmartBuoy system collects high-frequency data allowing patterns and processes to be studied at a higher temporal resolution than is possible with ship surveys. High-frequency chlorophyll and light data can be used to estimate primary production on a daily, monthly and annual basis in UK waters. The relationship between nutrient uptake and chlorophyll production can be investigated, and it is possible to calculate C:N ratios.

References

Cole, B.E. & Cloern, J.E. 1987. An empirical model for estimating phytoplankton productivity in estuaries. Marine Ecology Progress Series, 36, 299-305.

Campbell, J.W., Antoine, D., Armstrong, R., Arrigo, K., Balch, W., Barber, R., Behrenfeld, M., Bidigare, R., Bishop, J., Carr, M.E., Esaias, W., Falkowski, P., Hoepffner, N., Iverson, R., Kiefer, D., Lohrenz, S., Marra, J., Morel, A., Ryan, J., Vedernikov, V., Waters, K., Yentsch, C. and Yoder, J. 2002. Comparison of algorithms for estimating ocean primary production from surface chlorophyll, temperature, and irradiance. Global Biogeochemical Cycles, 16(3), Article Number 1035.

Gowen, R.J., Mills, D.K., Trimmer, M. and Nedwell, D.B. 2000. Production and its fate in two coastal regions of the Irish Sea: the influence of anthropogenic nutrients. Marine Ecology Progress Series, 208, 51-64.

*akd105@noc.soton.ac.uk