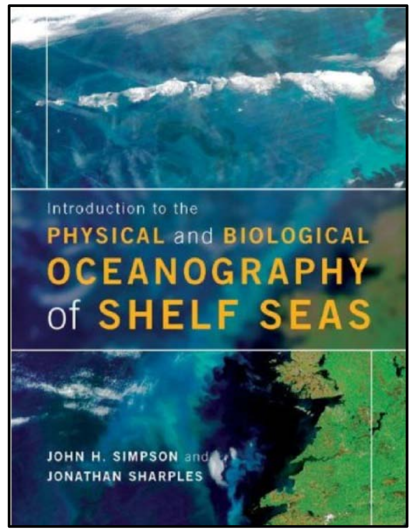
Observational Data

Shelf Sea Primary Production



Data Source:

This data was collected during cruise CD173 aboard the RRS *Charles Darwin* in the Celtic Sea, 15^{th} July – 6 August 2005.

Data Acknowledgement:

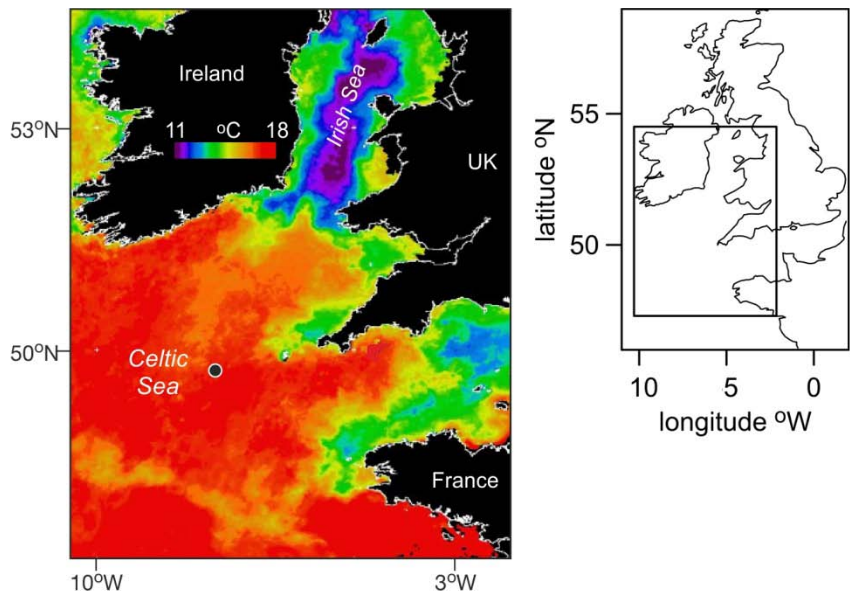
Data is supplied courtesy of the Anna Hickman, University of Southampton UK, and Jonathan Sharples, University of Liverpool UK. Funding for the work was provided by the UK Natural Environment Research Council, grant numbers NER/A/S/2001/00449 and NER/A/S/2001/00961.

Summary of data uses:

Typical vertical structures of temperature, salinity, density, chlorophyll, dissolved oxygen and inorganic nutrients in a stratified shelf sea; calculation of light attenuation coefficient; carbon fixation rates using incubation data; curve fitting (the photosynthesis-PAR curve); identifying acclimation of thermocline phytoplankton.

Oceanographic Background and Useful Papers:

The Celtic Sea is a seasonally-stratifying region of the NW European shelf. The onset of thermal stratification and the spring bloom typically occur in April, followed by 5 – 6 months of established stratification. Phytoplankton growth is largely regenerated production in the surface layer where nitrate is limiting, with new production within the sub-surface chlorophyll maximum (SCM) in the thermocline responding to a turbulent flux of nitrate from the bottom water.



Location map for the CTD profiles (black dot in the left image). The image on the left is a typical summer sea surface temperature image of the Celtic and Irish Seas. The warm surface water in the Celtic Sea indicates the stratified region, separated from the cooler, vertically mixed water in the Irish Sea and the western English Channel by tidal mixing fronts (see textbook sections 6.1 and 8.1). Image courtesy of NEODAAS, Plymouth Marine Laboratory.

The CTD being deployed from the RRS *Charles Darwin*. The vessel in the background is the RV *Prince Madog*.

Useful papers:

Hickman, A.E., P. M. Holligan, C. M. Moore, J. Sharples, V. Krivtsov, M. R. Palmer. 2009. Distribution and chromatic adaptation of phytoplankton within a shelf sea thermocline. *Limnology and Oceanography,* **54(2)**, 525-536.

Holligan, P. M., P. J. leB. Williams, D. Purdie, and R. P. Harris, 1984. Photosynthesis, respiration and nitrogen supply of phytoplankton populations in stratified, frontal and tidally mixed shelf waters. *Marine Ecology Progress Series,* **17**, 201-213.

Sharples, J., C. M. Moore, T. P. Rippeth, P. M. Holligan, D. J. Hydes, N. R. Fisher, & J. H. Simpson. 2001. Phytoplankton distribution and survival in the thermocline. *Limnology and Oceanography,* **46(3)**, 486-496.

Data:

All data is from position 49˚ 44.87’ N, 07˚ 40.10’ W. Depth was approximately 125 metres. This was referred to as station OB, and was chosen because it was in a region of relatively flat seabed.

1. CTD profiles at station OB, taken late afternoon on August 1st (CTD110) and pre-dawn on August 2nd (CTD120).
2. Inorganic nutrient sample data for CTDs 110 and 120.
3. Profile of PAR collected by a Satlantic optics profiler just before CTD110.
4. Results from incubations using C^{14} to determine photosynthesis-PAR curves for phytoplankton samples collected in the surface layer and from the SCM during CTD120.

Data Files:

<u>CTD data:</u>

Two files of CTD data are provided, `CTD110.dat` (1704 UTC, August 1st 2005) and `CTD120.dat` (0300 UTC, August 2nd 2005). The data is all from the down-profile of a Seabird 911plus CTD and rosette system (pictured above on page 2), with a Chelsea Instruments Aquatracka chlorophyll fluorometer, and a Seabird SBE43 dissolved oxygen sensor. Data has been bin-averaged into 1 metre intervals.

Data columns are:

depth	metres below sea surface.
temp01	temperature (ºC), from CTD primary sensor.
sal01	salinity (PSS), based on CTD primary T and conductivity sensors, calibrated

	against standard seawater to ±0.003.
sigt01	density (σ_θ, kg m^{-3}) calculated from temp01 and sal01.
chl	chlorophyll concentration (mg m^{-3}), calibrated against HPLC chlorophyll analyses of water samples to ±0.1 mg m^{-3}.
dox	dissolved oxygen concentration (μmol kg^{-1}), calibrated against Winkler titration of water samples to ±4 μmol kg^{-1}.
dox%	dissolved oxygen as a percentage of its saturation concentration.

<u>PAR data:</u>

The spreadsheet `Celtic_Sea_CTD110_PAR.xlsx` contains a vertical profile of PAR data (μE m^{-2} s^{-1}) measured by a free-falling Satlantic irradiance sensor just before CTD110.

<u>Primary production and nutrient data:</u>

The spreadsheet `Celtic_Sea_PPExperiment.xlsx` contains:

(1) Primary production measurements over a range of PAR for phytoplankton collected from a depth of 20 metres (i.e. within the surface mixed layer) and from within the peak of the sub-surface chlorophyll maximum. The results of fitting the data to a photosynthesis-PAR function are also included. See the textbook, section 5.1.4.

(2) Dissolved inorganic nutrient samples from CTDs 110 and 120.

Possible Analyses:

1. *Basic physical and biogeochemical structure of a stratified shelf sea. [Textbook Sections 5.1.6, 6.3.4, 7.3].*

   The profiles of temperature (or density), chlorophyll and dissolved oxygen from the CTD, along with the samples for dissolved inorganic nutrients, can be plotted to show the typical physical and biogeochemical water column structure for a post-spring bloom, summer stratified shelf sea. Letting the students loose to interpret the profiles will be instructive. There is a clear sub-surface chlorophyll maximum within the lower part of the thermocline, and associated with elevated (>100% saturation) dissolved oxygen. Nitrate is limiting in the surface layer, and there is a sharp nitracline in the lower portion of the chlorophyll maximum. It is turbulent mixing on this nitracline that supplies “new” bottom-layer nitrate to the phytoplankton in the chlorophyll maximum. Phosphate and silicate are also depleted in the surface layer. Phosphate probably is not a limiting nutrient, but silicate concentrations will be limiting for the diatoms.

2. *The vertical attenuation of PAR in a shelf sea, calculation of compensation and critical depths. [Textbook Sections 2.2.1, 5.1.5].*

   Plot a profile of PAR, and also take the natural logarithm of the radiation equation (e.g. equation 2.3 in the textbook) to produce a linear plot that allows a linear regression to get the attenuation coefficient. The daily mean surface PAR at this station was about 1700 μE m^{-2} s^{-1}, so knowledge of the attenuation coefficient can be used to generate a vertical profile of the daily-mean PAR. Students could use this as a basis for looking into the concepts of compensation and critical depth.

3. *Photosynthetic parameters in the photosynthesis-PAR curve, photo-acclimation. [Textbook Section 5.1.4].*

   The data from the experiments in spreadsheet `Celtic_Sea_PPExperiment.xlsx,` with measurements of primary production rates at different PAR values, can be fitted to the photosynthesis-PAR equation (e.g. equation 5.4 in the textbook). For this the student needs to know how to supply the equation into the fitting procedure in software such as Matlab, SigmaPlot, or Grapher. The solution to the fit is provided in the spreadsheet. The data come from a surface mixed layer population and from the sub-surface chlorophyll maximum. You will find that the deeper population has a lower value of I_k (equation 5.5 in the textbook), which can be interpreted in terms of photoacclimation of the phytoplankton. The apparent photoinhibition seen in the data from the sub-surface chlorophyll maximum at high PAR is also worth discussing. The phytoplankton are being exposed to light in the experiment that they would not normally experience in the thermocline; the damage arises because they are acclimated to low light.

4. *Water column primary production. [Textbook Section 7.3].*

   Either the photosynthesis-PAR data or the resulting curve equation can be used to integrate the primary production within the photic zone. Using the daily-mean surface PAR irradiance of 1700 μE m^{-2} s^{-1}, along with the measure of the PAR vertical attenuation coefficient, a PAR profile can be calculated down to the 1% light level. If the photosynthesis-PAR curve is know, then integrating the primary production is simply a case of stepping down the light profile in, say, 1 metre increments, calculating the photosynthesis rate, and producing an integral photosynthesis rate in g C (g Chl)$^{-1}$ m^{-2}

d^{-1} (taking care with the time units). Using the chlorophyll concentration profile from CTD120 allows this to be converted into g C m^{-2} d^{-1}. The students would have to make a sensible choice concerning which parts of the water column to apply the surface layer photosynthesis curve and which the sub-surface maximum curve (e.g. perhaps by looking at the temperature profile and the surface layer physical structure). It is also possible to integrate the photosynthesis using the experiment data alone, without the results of the curve fitting. The added complication here is to assign depth increments within which each of the photosynthesis-PAR data pairs is associated. You could also consider the implications of turbulent flux of nitrate which was measured at this station as 2 mmol m^{-2} d^{-1} into the base of the thermocline; assume phytoplankton accessing this nitrate source are in Redfiled C:N and an estimate of the *f*-ratio of the primary production can be made.
