Phytoplankton biomass, photosynthesis and primary production along the NW Iberian peninsula

G.H. Tilstone, F.G. Figueiras and L.M. Lorenzo.

Instituto de Investigaciones Marinas, C.S.I.C., Eduardo Cabello 6, 36208 Vigo, Spain.

ABSTRACT

Five hydrographic conditions can occur along the NW Iberian Peninsula during a typical yearly cycle. These are upwelling, upwelling relaxation, downwelling, stratification and poleward flow. Primary production ($PP_{(PUR)}$) was determined using a spectral model based on phytoplankton useable radiation (PUR) derived from the light absorption coefficient of phytoplankton during two WP II cruises (*BG9714C* and *CD110B*) and one WP I cruise (*CD114A*). Phytoplankton counts were also determined on these three cruises. The cruises covered four of the five hydrographic conditions (upwelling, upwelling relaxation, stratification and poleward flow) and therefore enabled us to compare phytoplankton biomass and primary production during different hydrographic regimes. During all cruises flagellates dominated the phytoplankton and were highest during upwelling. Cyanobacteria were also high during all cruises and Diatoms showed the highest biomass during wind relaxation. Primary production was significantly higher during upwelling ($F_{3,18}$=23.05, P<0.001; mean 2921±626 mgC m^{-2} d^{-1}) compared with all other hydrographic conditions. The poleward current exhibited the lowest values (320±69 mgC m^{-2} d^{-1}).

INTRODUCTION

Primary production in estuarine and upwelling ecosystems is typically the highest of all ocean ecosystems (Ryther 1969, Harding *et al.* 1986). The specific pattern of physical processes in which upwelling systems results in a particular nutrient regime (Legendre 1981) which determines the primary production and phytoplankton species composition (Barber and Smith 1981). Primary production has been correlated with upwelling and downwelling events (Small and Menzies 1981) and is enhanced (Minas *et al.* 1982) or reduced (Huntsman and Barber 1977) by the strength of vertical advection followed by the residence time of stratification. Diatoms often dominate the phytoplankton assemblage during upwelling conditions along the NW Iberian Peninsula (Estrada 1984), although flagellates usually constitute as much as 90% of the biomass (Bode *et al.* 1994). To date, there is little information on primary production along the NW Iberian shelf. Bode *et al.* (1994) found higher production values during spring and summer upwelling events when net-phytoplankton were dominant and lower values during stratified and winter mixing periods when nano-phytoplankton were more abundant.

METHODS

Phytoplankton identification and biovolume.

Phytoplankton samples were preserved in Lugol´s iodine and sedimented in composite sedimentation chambers. Diatoms, dinoflagellates, flagellates larger than 20 µm and ciliates (oligotrichous and peritrichous) were identified and counted to the species level where possible, using an inverted microscope. Cyanobacteria, autotrophic pico- (≤ 2µm) and nanoplankton were identified and counted by epifluorescence microscopy. Further details of the counting procedure for both inverted and epifluorescence counts are given in the first scientific OMEX II-II report. The dimensions of each of the species identified were measured and cell volumes were determined by approximation to the nearest geometric shape and then converted to phytoplankton carbon.

Photosynthesis-irradiance parameters (P-E) and integrated primary production

The determination of broad-band P-E parameters and light absorption spectra of phytoplankton is described in the first scientific OMEX II-II report. Samples were inoculated with 1.85 x 10^5 Bq (5 µCi) of ^{14}C-labelled bicarbonate and incubated for 2 to 3 hrs in lineal incubators illuminated by Osram tungsten halogen lamps with dichroic reflector and Deco glass covers (50 W, 12 V). In addition to broad-band photosynthetic parameters, the photosynthetic useable radiation and maximum quantum yield of phytoplankton were determined from phytoplankton absorption spectra. The photosynthetic active radiation absorbed by phytoplankton [E_{PUR} (µmol m^{-3} s^{-1})] at each position in the incubators was estimated according to Dubinsky (1980):

$$E_{PUR} = \int_{400}^{700} a_{ph}(l) \cdot E_q(l) d(l)$$

where $a_{ph}(l)$ is the phytoplankton spectral absorption coefficient.

The maximum quantum yield of carbon fixation [f_m mol C fixed (mol photons)$^{-1}$ absorbed] was determined by fitting the photosynthetic rates Pm (mgC m^{-3} h^{-1}) to the photosynthetic radiation absorbed by phytoplankton [E_{PUR} (µmol m^{-3} s^{-1})]:

$$P_z = P_m \left[1 - \exp\left(- f'_m \cdot E_{PUR} / P_m\right)\right]$$

where $f_m = 0.0231 \cdot f'_m$. The factor 0.0231 convert milligrams of carbon to moles, µmol of photons to moles and hours to seconds. Since maximum photosynthetic rate is wavelength independent (Pickett and Myers 1966) then $P_m / Chl = P_m^B$, the light-saturated Chl-specific rate of photosynthesis (mgC mg Chl^{-1} h^{-1}).

Integrated primary production $PP_{(PUR)}$ using the action spectrum of phytoplankton inferred from $a_{ph}(\lambda)$ measurements was calculated every hour over 24 hours and every metre in the water column to 0.1% of the surface irradiance as follows:

$$PP_{(PUR)} = \int_{Z=0}^{Z=0.1\%} \int_{T=0}^{24} Chla(z) P_m^B(z) \left[1 - \exp\left(- E_{PUR}(t,z) / E_{K(PUR)}(z)\right)\right] dz.dt$$

where $E_{k(PUR)}$ is the light saturation parameter of phytoplankton useable radiation = P_m / f'_m.

RESULTS AND DISCUSSION

***Task II.8.1** Spatial and Temporal Distribution of Phytoplankton Biomass, Species, Pigments and Their Remote Sensing*

The water column was highly stratified during *BG9714C*, with high temperatures >18.0°C at the surface and a high salinity core (>36.0 pss) located over the shelf break. Towards the end of the cruise there was evidence of upwelling at Cape Finisterre. Chl *a* levels were relatively low for typical summer conditions along the NW Iberian Peninsula (mean 0.60±0.07 mg m^{-3}). Two Chl *a* maxima (0.7 mg m^{-3}) occurred at 60 m; one associated with the high salinity core and the other coincided with less saline coastal water.

During *CD110B* there was a poleward movement of warm, saline, northwards towards Cape Finnisterre, which blocked outwelled, less saline water of coastal origin. Chl *a* levels associated with the poleward flow were comparatively low (max = 0.3 mg m^{-3}) and higher in outwelled coastal surface water (>0.5 mg m^{-3}).

The carbon biomass of phytoplankton along the coast of Galicia during *BG9714C* (Fig. 1a) had a characteristic coastal - ocean distribution, with higher diatom standing stock near to the coast and higher flagellate and dinoflagellate biomass at the shelf break and oceanic stations. Flagellates were the most abundant phytoplankton group and accounted for 64% of the total phytoplankton biomass which increased from the southern coast to northern oceanic stations with a maximum (>65.0 $\mu g\ l^{-1}$) situated at station O2P26 along 42.6°N. Cyanobacteria constituted 29% of the total biomass and were more abundant at coastal stations between 42.6 and 43.0°N, at oceanic stations along 42.15°N (>20.0$\mu g\ l^{-1}$) and significantly lower along the shelf. Diatoms and dinoflagellates accounted for only 0.4 and 6% of the total biomass. Dinoflagellate biomass was low towards the coast and increased oceanward (max. 6.32 $\mu g\ l^{-1}$ at station O2Q21). The diatom biomass showed the opposite trend being higher at the coast (max 0.36 $\mu g\ l^{-1}$ at station O2Q19) and successively lower towards the ocean.

During the winter poleward conditions of *CD110B*, flagellates accounted for the highest biomass (60% of the total; Fig. 1b) and were slightly higher in outwelled water from the coast (range; 21 to 45 $\mu g\ l^{-1}$) than in the poleward (range 11 to 40 $\mu g\ l^{-1}$; Fig. 1b). Cyanobacteria accounted for 35% of the phytoplankton biomass and were more abundant in the poleward (range 6 to 25 $\mu g\ l^{-1}$) than at the coast (range; 8 to 12 $\mu g\ l^{-1}$). Both the diatoms and the dinoflagellates were in low abundance and accounted for only 2% of the phytoplankton biomass.

***Task II.8.3** Parameterisation of Primary production: Photosynthesis-Irradiance Relationships*

Integrated Primary Production ($PP_{(PUR)}$) is presented in Fig. 2. During BG9714C, the range in $PP_{(PUR)}$ was 773 to 1989 mgC $m^{-2}\ d^{-1}$, with lower values at southerly stations and higher values at northerly coastal stations (Fig 2a), which coincided with the start of upwelling at 43.0°N. There were no significant differences in PP between coastal and oceanic stations ($F_{1,12}$=0.88, P=0.366). The range in $PP_{(PUR)}$ during cruise *CD110B* was (251 to 923 mg m^{-3}; Fig 2b). Within the winter poleward current (stations P200 and P1000) PP was the lowest of all hydrographic conditions surveyed (mean = 320 ± 69 mgC $m^{-2}\ d^{-1}$). PP was higher at station V110 in outwelled coastal water.

Photosynthetic parameters for these two cruises have already been given in the first scientific OMEX II-II report.

***Task I.3** Nutrient dynamics, Primary production, biomass and phytoplankton*

CD114A was a 10-day Lagrangian experiment along the shelf of the NW Iberian Peninsula. A buoy was used to track newly upwelled water on the shelf on JD 214, which travelled southwards and offshore under the influence of northerly winds until JD 217, after which wind relaxation slowed the trajectory of the buoy. The experiment lasted 5 days and the buoy was then repositioned on the shelf to study the 24-h variation in these parameters. Two distinct hydrographic phases were characterised from CTD temperature, salinity, density and Chl *a* profiles. During the first two days there was upwelling of cold, nutrient rich water (ENAW) into the photic zone (mean Temp 14.32°C, Sal 35.67 pss at 45 m) followed by a relaxation event (mean Temp. 14.74°C, Sal. 35.71 pss at 45 m). Chl *a* levels were lower during the initial upwelling (1.5 mg m^{-3} at 20 m).

During *CD114A* the flagellates were also the most abundant phytoplankton group and accounted for 53% and 40% of the phytoplankton biomass during upwelling and wind relaxation events respectively, reaching a maximum of >75 $\mu g\ l^{-1}$ on the second day of the Lagrangian experiment (Fig. 1c). Cyanobacteria constituted 40% of the total biomass during upwelling, with >85 $\mu g\ l^{-1}$ on the first day of the experiment. There was a slight decrease in cyanobacteria during wind relaxation (max 60 $\mu g\ l^{-1}$) when they formed 36% of the total biomass. The diatom biomass was initially low during upwelling (=1.0 $\mu g\ l^{-1}$) and made up only 2.5 % of the total biomass, but increased by >20 times (max. 30 $\mu g\ l^{-1}$). The dinoflagellates had the lowest biomass during upwelling and wind relaxation (max 4$\mu g\ l^{-1}$ during upwelling, 6.45 $\mu g\ l^{-1}$ during wind relaxation) which accounted for only 2% of the biomass.

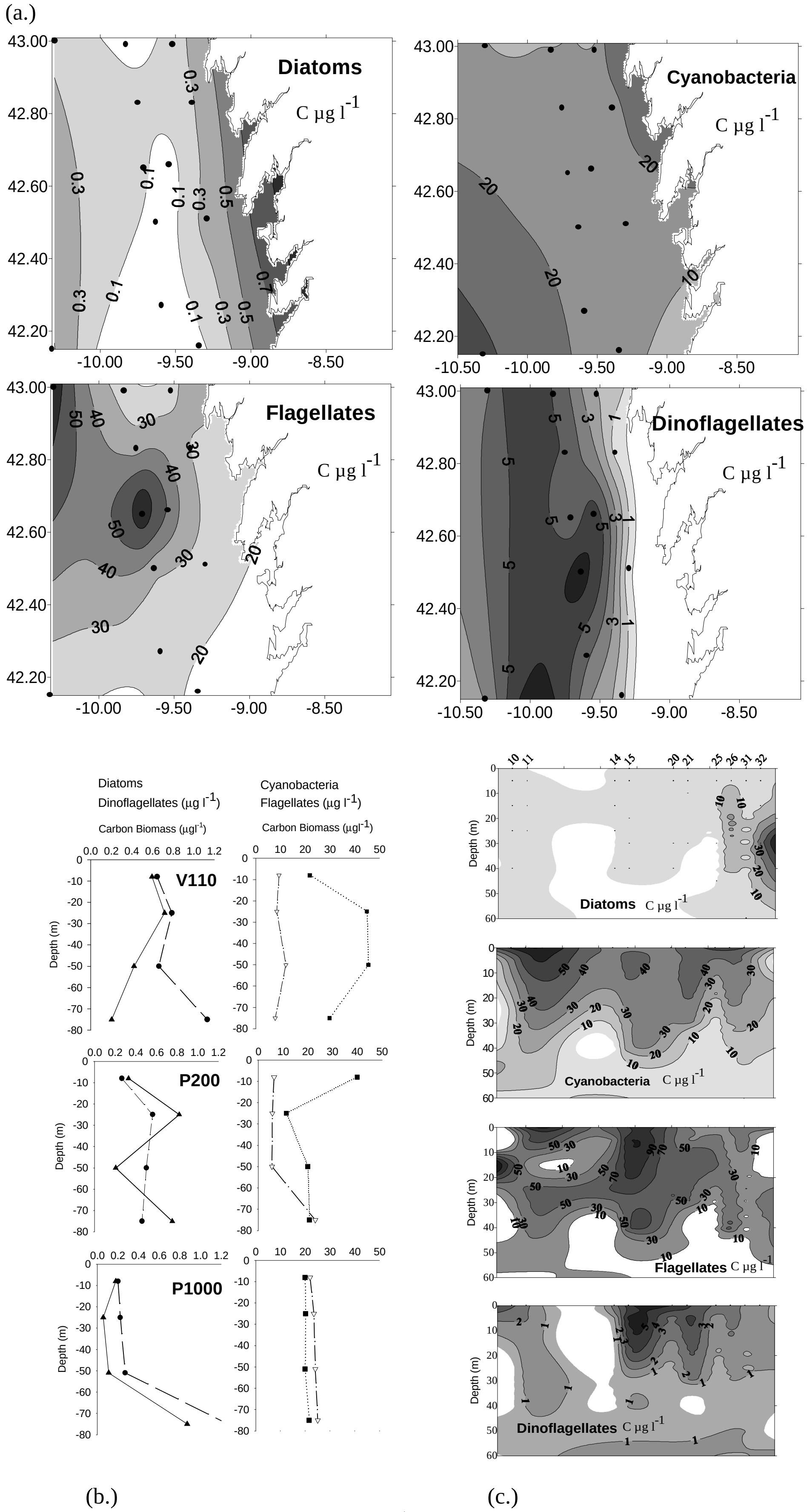
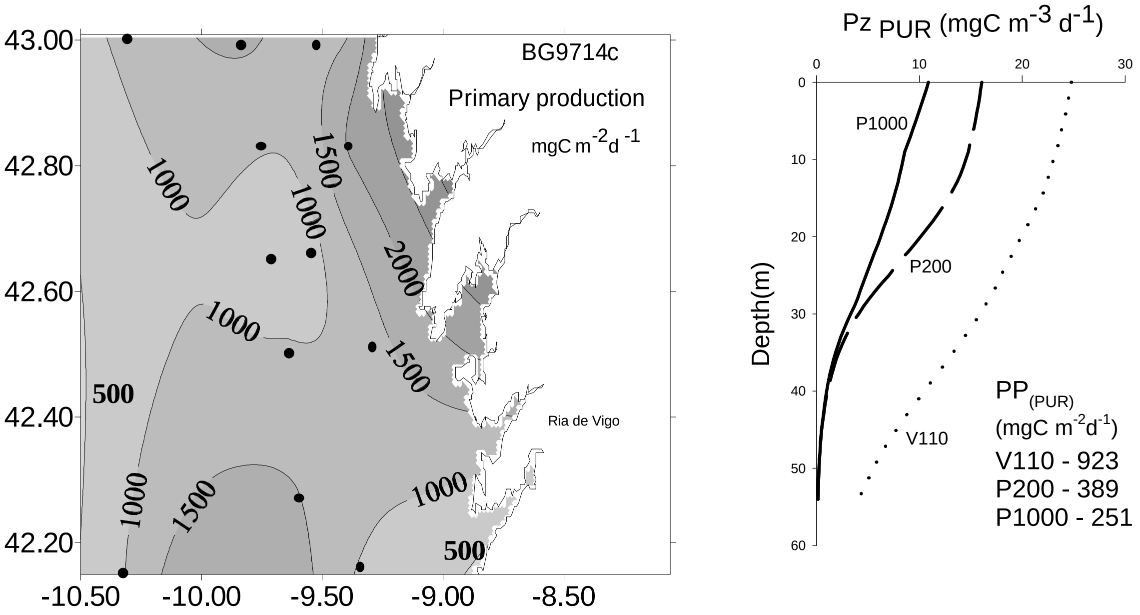


Figure 1. Carbon biomass (µgl^{-1}) of major phytoplankton groups cruise *BG9714C* (a.), *CD110B* (b.) and *CD114A* (c.).



(a.) (b.)

Fig 2. Integrated Primary production $PP_{(PUR)}$ along the NW Iberian Peninsula during *BG9714C* (a.) and *CD110B* (b.).

Date	CTD	Integrated PP PUR ($mgC\ m^{-2}\ d^{-1}$)	Date	CTD	Integrated PP PUR ($mgC\ m^{-2}\ d^{-1}$)
03.08.98	10	2130	06.08.98	25	2727
	11	2458		26	2000
04.08.98	14	3171	07.08.98	31	1867
	15	2810		32	1831
05.08.98	20	3939			
	21	3018			

Table 1. Integrated Primary Production, PP ($mgC\ m^{-2}\ d^{-1}$) during cruise *CD114A*.

The range in $PP_{(PUR)}$ during *CD114A* was 1780 to 3953 $mgC\ m^{-3}\ d^{-1}$ (Table 1). PP gradually increased during upwelling and significantly decreased during wind relaxation ($F_{1,9}$=21.72, P=0.002). The highest values during the upwelling event coincided with a short-term relaxation event on 5th August 1998. Most of the water column primary production was in the first 20 m of the water column on days 1 and 2 and by day 3 there was a maximum at 5 m. On day 5, *in situ* primary production in the upper 20 m was reduced due to the deepening of the Chl *a* maxima to 30 m as the buoy moved off-shore. When $PP_{(PUR)}$ data from all hydrographic conditions was compared, $PP_{(PUR)}$ was significantly higher during upwelling ($F_{3,18}$=23.05, P<0.001; mean 2921 ± 626 $mgC\ m^{-2}\ d^{-1}$).

REFERENCES

Barber R.T., Smith R.L. (1981) Analysis of marine ecosystems. Academic Press, New York, p 31-68.
Bode A., B. Casas, E. Fernandez, E. Marañon, P. Serret, M. Varela. (1993) ICES. J. Mar. Sci. 53,1-10.
Bode A., B. Casas, M. Varela. (1994) Sci. Mar. 58, 131-141.
Dubinsky Z. (1980) In: Primary production in the sea (Ed) Falkowski P.G. Plenum Press, pp. 83-97.
Estrada, M. (1984) J. Plankt. Res. 6, 417-434.
Harding L.W.Jr., B.W. Meeson, T.R. Fisher Jr. (1986) Est. Coast. Shelf. Sci., 23, 773-806.
Huntsman S.A., R.T. Barber. (1977) Deep-Sea Res. I, 24, 25-33.
Legendre, L. (1981) Ecohydrodynamics, 191-207.
Minas, H. J., T.T. Packard, M. Minas, B. Coste. (1982) J. Mar. Res. 40, 615-641.
Ryther J.H. (1969) Science 33:149-163.
Small LF, Menzies DW (1981) Deep Sea Res 28A:123-149