Transfer and Fluxes of Elements in Relation with the Carbon Cycle in the Iberian Upwelling Margin

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INTRODUCTION

During the second project year of OMEX II-II, ULB-b participated in the *Belgica BG9815C* cruise (27 June - 7 July 1998), during which a slope survey along the OMEX II-II O2N, O2P and O2S transects off the NW Iberian margin was conducted. Figure 1 shows the area and the stations investigated. Classical parameters such as temperature, salinity, dissolved oxygen, chlorophyll and nutrients were measured. Process studies on the assimilation of carbon and phosphorus were also carried out during field investigations. Suspended matter was collected by continuous centrifugation and by *in situ* pumping of large volumes of water at various depths, and was analysed for its composition in major, minor and trace elements. This report presents the results obtained during the *BG9815C* cruise in addition to data on the particulate composition of samples collected by sediment traps at the IM1 and IM2 sites along the O2P transect. The objectives are to evaluate primary production and assimilation of phosphorus in the Iberian upwelling region and related fluxes of particulate elements.

Prior to the cruise, the remote sensing images show a narrow band of upwelled cold water all along the Galician coast (Figure 2). At the end of the cruise (5 July 1998) Sea Surface Temperature imagery shows strong upwelling off Cape Finisterre, while SeaWiFS chlorophyll data reveal a highly productive zone with the formation of filaments near the Vigo region (Figure 3).

Vertical profiles of temperature along O2N, O2P and O2S transects are shown in Figures 4a, 5a and 6a. They confirm the strong upwelling near the coast off the Cape Finisterre area between 42.5°N and 43°N. Repeated CTDs reveal the importance of the internal waves in the area.

RESULTS AND DISCUSSION

Task II.4.1 Nutrient oceanography

Two sets of nutrient samples were collected. One set was analysed on board for phosphate and silicate by colorimetry according to the methods described in Grasshoff *et al*. (1983). The second set was kept frozen for later analyses in the laboratory. Vertical profiles of the phosphate concentrations are shown in Figures 4c, 5c and 6c. High surface concentrations of nutrients are found at two inshore stations along the O2P and O2N transects where upwelling was occurring. Nutrients become rapidly depleted when moving westward from the upwelling zone.

Concentrations of nitrate and phosphate for waters taken between 50 and 1200 metres show strong correlation with an N/P ratio of 17, close to the classical Redfield ratio observed for these elements (Figure 7). Figure 8 shows the correlation between dissolved silicate and phosphate, revealing strong difference in silicate concentration of surface waters (upper 200 m) and deeper waters (> 200 m). Surface waters are less enriched in Si with a Si/P ratio of 5.2, while deeper waters contains more Si with a Si/P ratio of 17.9. This suggests a fast uptake of dissolved silicate, and indicates that this element could rapidly become limiting in the euphotic zone for diatoms.

Task II.5.4 Pigment biomarker

Chlorophyll *a* samples were collected on GF/F filters in the upper 200m. They were quickly frozen in liquid nitrogen and kept in a deep freezer. The chlorophyll *a* contents were later determined in the laboratory by fluorometry (Yentsch and Menzel, 1963).

Vertical distributions of chlorophyll *a* concentrations indicate a maximum at the surface near the coast where upwelling prevails (Figures 4b, 5b and 6b). When moving offshore, the maximum chlorophyll *a* concentrations are found at sub-surface. This observation is coherent with the fact that the offshore surface waters are depleted in nutrients.

Task II.8.2 Intercalibration of primary and new production

An intercalibration exercise on ^{14}C (PML-c, ULB-b and IIM), ^{33}P (PML-c and ULB-b) and ^{15}N (PML-c and VUB) will be conducted in Plymouth during the period from 19 to 21 July 1999.

Task II.8.3 Parameterisation of Primary Production

Potential primary production has been determined as a function of light intensity (0-600 µE m^{-2} s^{-1}) during the *BG9815C* cruise by performing ^{14}C incorporation experiments. The results obtained have allowed the characterisation of the photosynthetic properties of the phytoplankton based on the classical Platt *et al*. (1980) equation :

$$\mu^{chl} = \mu^{chl}_{max} \left[1 - \exp(-\alpha \; I / \mu^{chl}_{max})\right] \exp(-\beta \; I / \mu^{chl}_{max})$$

where μ^{chl}_{max} is the maximum photosynthetic capacity, α the photosynthetic efficiency, β the index of photoinhibition and I the incident photosynthetically available radiation (PAR).

Figure 9 shows as an example the carbon uptake rate as a function of light intensity for an upwelling station (St. 33) and an offshore station (St. 38) at two depths along the O2N transect. The results compared to the theoretical curves show that in general the plankton at depth exhibits a higher photosynthetic efficiency and may be affected sometimes by photo-inhibition (Table 1). The potential production is one order of magnitude higher in the upwelling region compared to the offshore stations.

Task II.8.5 Assimilation and regeneration of phosphorus

Similar to carbon incorporation, photosynthetic parameters for phosphorus assimilation can be obtained based on the production *vs.* light intensity curves. The results indicate a higher photosynthetic efficiency and a slight photo-inhibition for species in deeper waters compared to those in the surface (Figure 10). Notice the important uptake under dark conditions indicating the importance of the incorporation unrelated to photosynthesis.

Results on the incorporation of phosphorus under constant light (L) and dark (D) conditions conducted along the O2N transect (Stations 33 - 38) indicate a higher assimilation rate in the upwelling zone than in the open ocean (Figure 11). The phosphate uptake was dominated by the smaller size fraction (0.2-2 µm) of plankton, except for stations near Cape Finisterre where stronger upwelling is stronger.

Menten-Michaelis kinetics for the phosphorus assimilation were determined at a limited number of stations situated more offshore. Figure 12 shows that a higher maximum specific uptake rate (V_{max}) is obtained where higher production is observed, but with similar half-saturation constants (K_s) close to those observed for oligotrophic waters.

Addition of various inhibitors allows the evaluation of phosphorus assimilation by various fractions. Figure 13 summarizes the data obtained for stations situated along the transect O2P. The results on experiments where the antibiotics (a mixture of streptomycin and polymyxin) were added to the samples confirm the important role of the microbial activity in the phosphorus cycling. The uptake of phosphorus related to photosynthesis is important only in strong upwelling areas and the contribution of heterotrophic bacterial activity to total phosphorus assimilation becomes dominant when moving offshore. The fraction due to mineral adsorption is not negligible, indicating higher concentration of the particulate phase especially in the coastal area. The non-photosynthetic fraction corresponds to that incorporated by phytoplankton in the dark, excluding that assimilated by the bacteria and by the mineral phase.

Task II.8.6 Spatial and seasonal distribution of primary and new production

Incubation experiments with ^{14}C were also performed under constant light conditions to evaluate the potential primary production. Fractionated production was performed on three size classes (>20 µm, 20-2 µm and <2 µm). The results show that primary production is dominated by larger size fraction (>2 µm) where upwelling prevails, while the reverse trend is observed for offshore stations (Figure 14).

Integrated production was evaluated at each station based on the photosynthetic parameters obtained under *Task II.8.3*, vertical distribution of chlorophyll concentrations and light intensity. The results show higher integrated primary production in the upwelling region adjacent to the coast, decreasing when moving offshore (Figure 15a). The highest production observed at Station 20 along transect O2P can be related to the establishment of an older upwelling event compared to Station 33 situated at the northern end of the Iberian margin where the development of phytoplankton biomass has just started. This agrees with the observation made by Frankignoulle and Borges (this volume) that the surface waters near station 20 was highly undersaturated in pCO_2 with respect to the atmosphere. Light profiles measured during the cruise indicate that the euphotic zone in the coastal region did not exceed 20 metres at Station 20 where the maximum biomass was observed (Figure 15b). When normalised with respect to the chlorophyll *a* concentration, the integrated primary production obtained by ULB-b in the Vigo area during the *BG9815C* cruise is of the same order of magnitude as that evaluated by PML-c during the *CD114* cruise which took place in August 1998 (Joint *et al*., this volume).

Task II.5.1 Biomineral and lithogenic composition

Particulate matter collected by continuous centrifugation, *in situ* pumping using Stand Alone Pumps (SAP) and sediment traps were analysed for major, minor and trace elements in order to distinguish the biogenic from the lithogenic fraction. All analyses have been processed, except for SAP samples collected during the *BG9815C* cruise which is close to completion.

The composition of major components (organic, carbonate and lithogenic) of the surface suspended matter collected by continuous centrifugation during the *Belgica BG9714* and *BG9815* cruises are shown in Figures 16 and 17 respectively. The results indicate that particulate material in surface waters during the June-July period are rich in organic matter with an average concentration of 65-70%. The carbonate content does not exceed 20% and is comparable to the lithogenic content.

Task II.11.2 Seasonal vertical fluxes from biogeochemical and morphometric analyses of suspended and sediment trap material

Suspended matter collected by traps for the period from July 1997 to February 1998, installed along the O2P transect, has been analysed for their particulate elemental composition. Figure 18 shows the major, minor and trace component contents as a function of particulate aluminium, an indicator of the lithogenic fraction, for selected elements. It indicates that particulate Si, Fe, Mn and K are well correlated with particulate Al, confirming their terrigenous origin. Particulate Ca, an indicator of the calcium carbonate content, shows an anti-correlation with Al. Particulate Co, taken as an example for trace elements, exhibits a moderate correlation with particulate Al. The particulate Ca and Al contents are plotted in Figure 19, showing the seasonal evolution of the composition of the carbonate and lithogenic components for the period considered. The dominant presence of the lithogenic phase in the two traps situated at 1100 m depth indicates a rapid degradation of organic matter in the water column. It is presently difficult to evaluate the seasonal trend of elemental fluxes, because the data on mass fluxes have not yet been made available by IfM and thus fluxes cannot be calculated.

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Platt T., C. L. Gallegos and W. G. Harrison (1980) Photoinhibition of photosynthesis in natural assemblages of marine phytoplankton. *J. Mar. Res.*, **38**, 687-701.

Yentsch C.S. and D.W. Menzel (1963) A method for the determination of phytoplankton chlorophyll and phaeophytin by fluorescence. *Deep-Sea Res.*, **10**, 221-231.

Table 1. Photosynthetic parameters determined from experiments conducted under variable light conditions.

Station	Depth (m)	Chlorophyll *a*	μ^{chl}_{max}	α	I_k	β
2	8	0.399	6.32	0.02707	233	4E-05
2	59	0.319	1.84	0.03762	49	
4	9	0.231	7.43	0.03377	220	3E-05
4	34	0.303	4.16	0.06337	66	
20	9	5.501	3.49	0.01702	205	
20	39	0.351	2.36	0.02222	106	
23	9	0.269	4.33	0.02900	149	
23	59	0.374	3.88	0.02727	142	
26	9	0.224	4.02	0.02250	179	
26	59	0.427	2.02	0.04215	48	
33	9	1.694	4.75	0.02196	216	
33	39	0.711	7.09	0.04557	156	
35	9	1.044	3.45	0.02184	158	
35	62	0.232	2.33	0.03103	75	
38	8	0.23	4.12	0.02348	176	
38	60	0.366	1.64	0.04590	36	5.0E-05

Chlorophyll *a* in μg l^{-1}, μ^{chl}_{max} in μg C (μg Chl)$^{-1}$ h^{-1}, α and β in μgC (μg chl)$^{-1}$ (μE m^{-2} s^{-1})$^{-1}$ h^{-1}, I_k in μE m^{-2} s^{-1}

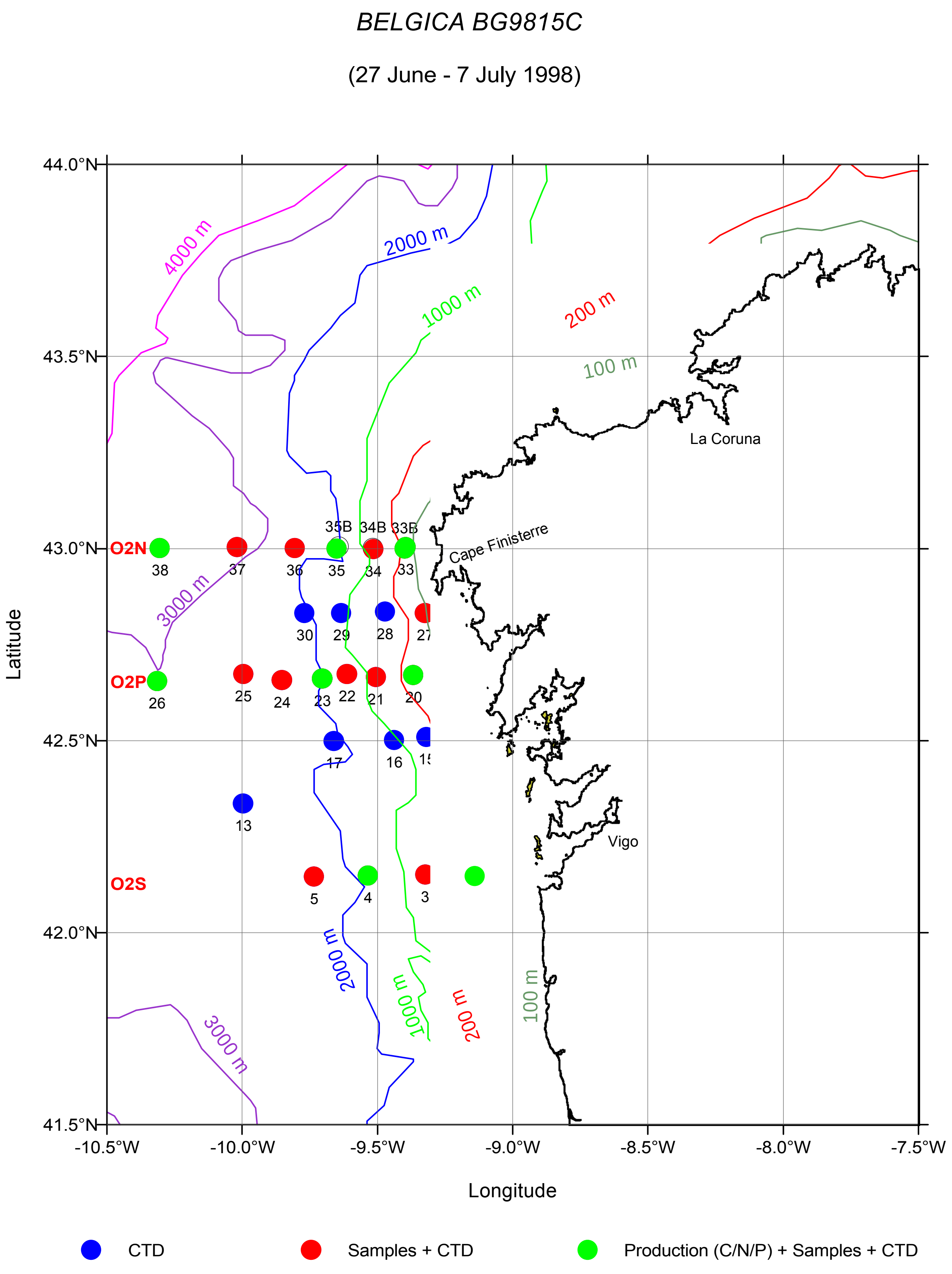


Figure 1. Sampling locations of the *Belgica BG9815C* cruise.

22 June 1998

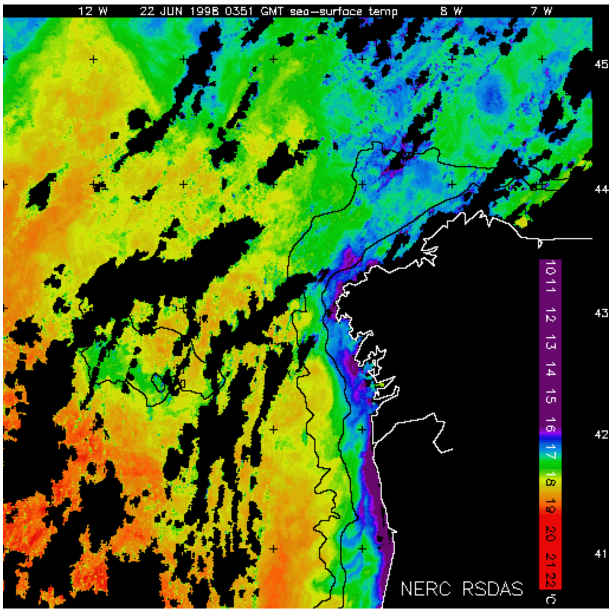


Figure 2. Sea surface temperature in the NW Iberian margin prior to the *Belgica BG9815C* cruise. Satellite image received by the NERC Dundee Satellite Receiving Station, and processed by Peter Miller at the NERC-CCMS Remote Sensing Group in Plymouth.

5 July 1998

(a) SST

(b) Chlorophyll

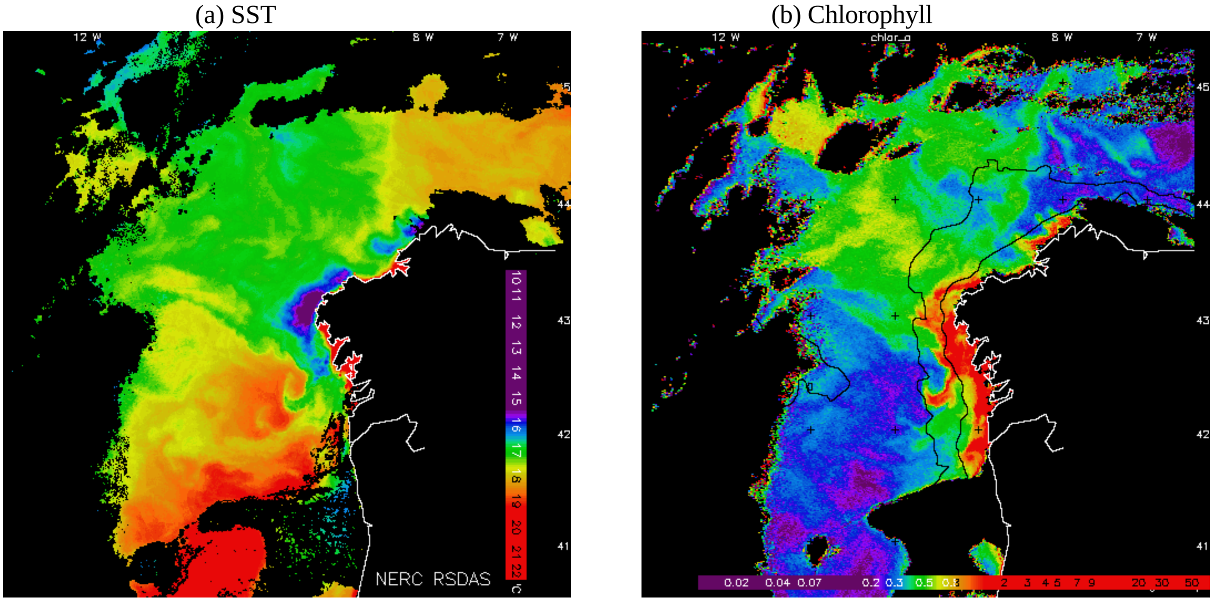


Figure 3. Distribution of sea surface temperature (a) and satellite chlorophyll (b) along the Galician coast at the end of the *BG9815C* cruise. Satellite images received by the NERC Dundee Satellite Receiving Station, and processed by Peter Miller at the NERC-CCMS Remote Sensing Group in Plymouth.

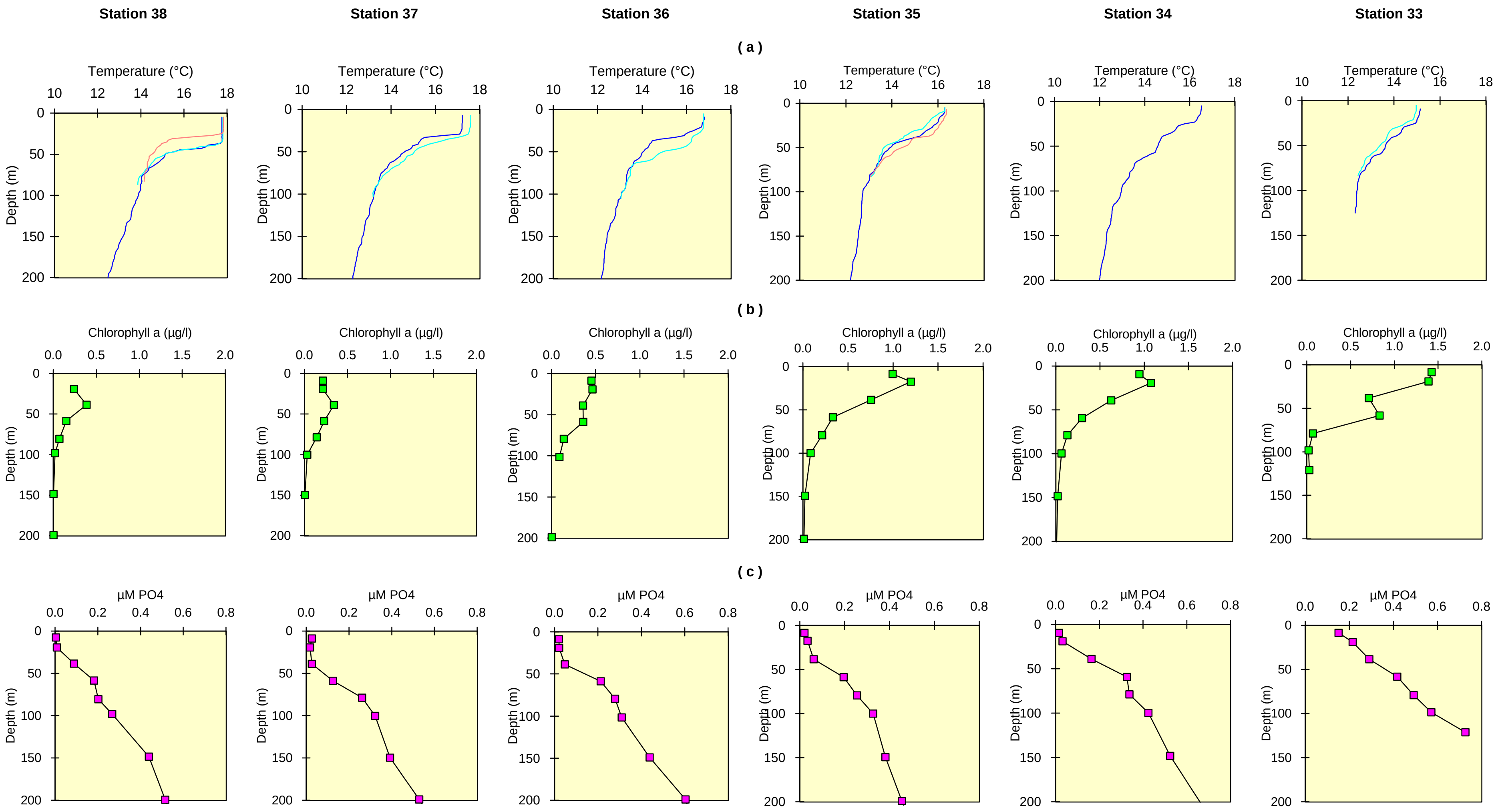


Figure 4. Vertical profiles of (a) temperature, (b) chlorophyll *a* and (c) phosphate in the upper 200 m along the transect O2N.

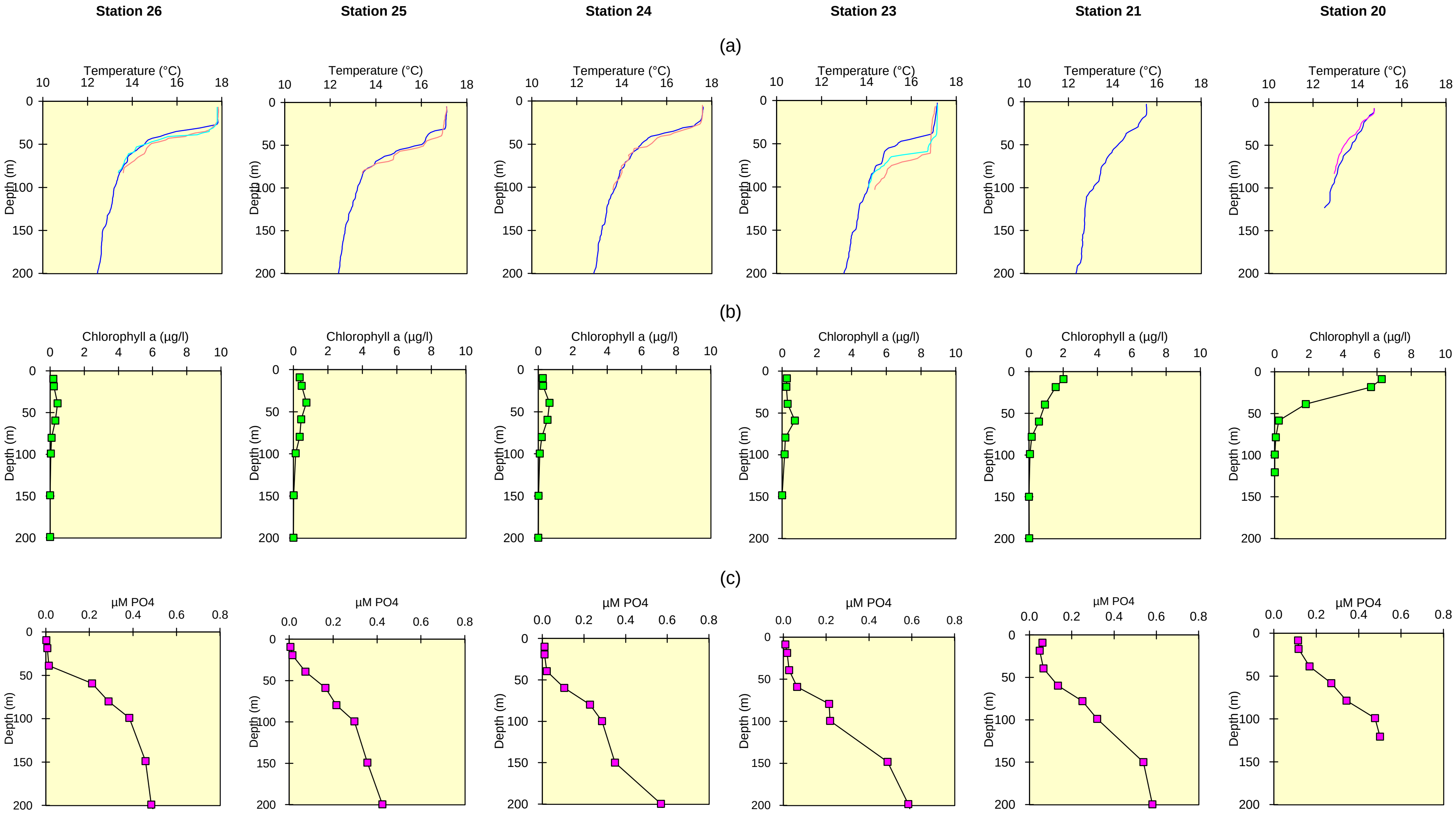


Figure 5. Vertical profiles of (a) temperature, (b) chlorophyll *a* and (c) phosphate in the upper 200 m along the transect O2P.

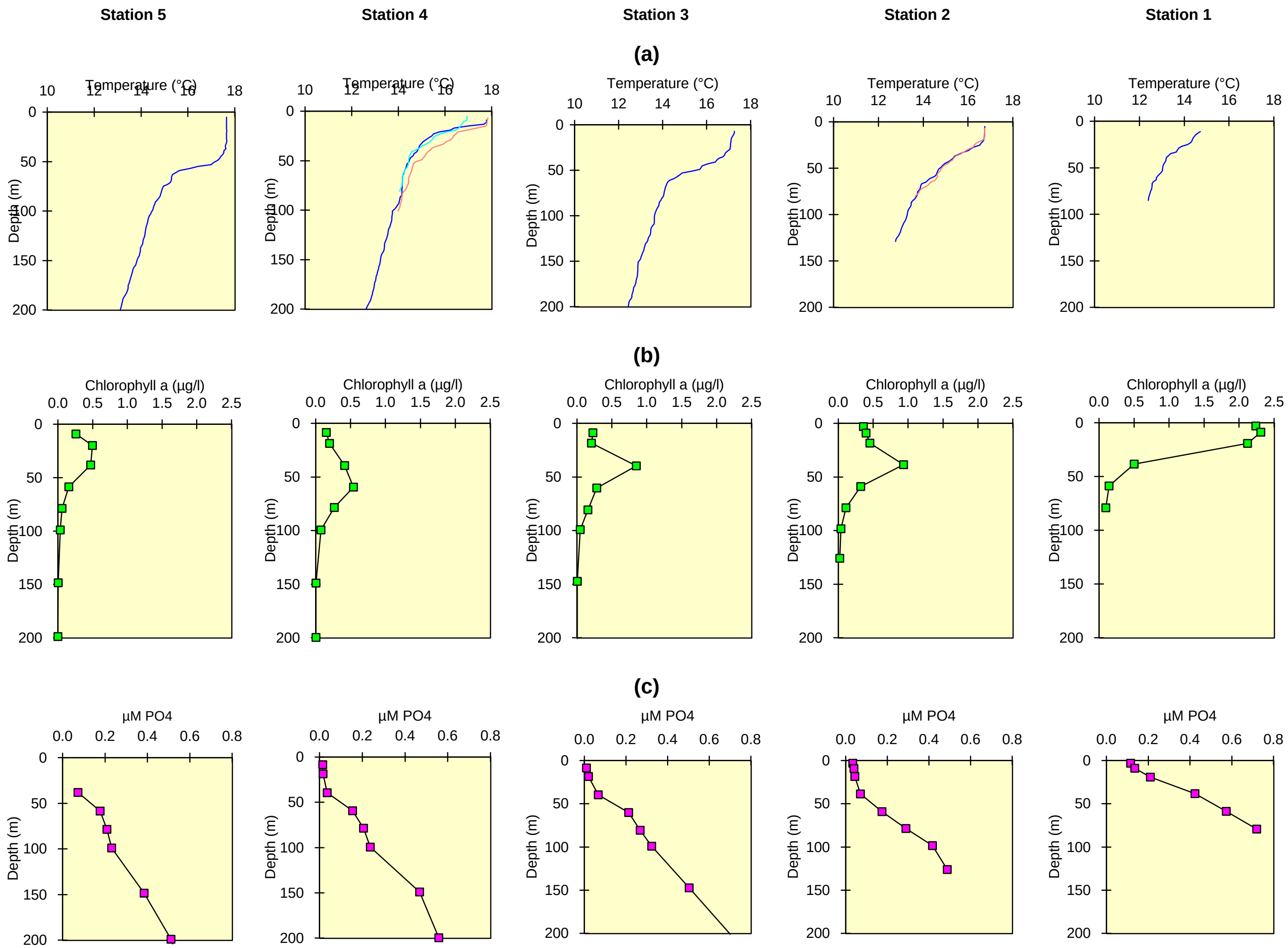
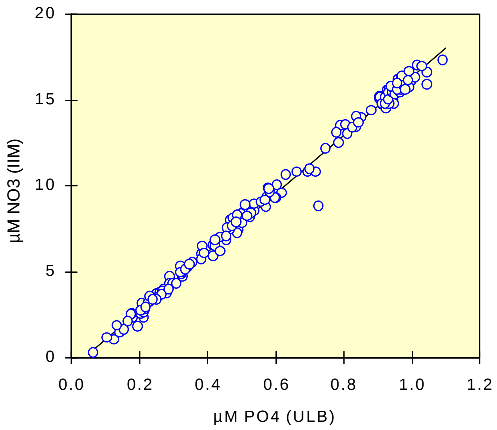


Figure 6. Vertical profiles of (a) temperature, (b) chlorophyll a and (c) phosphate in the upper 200 m along the transect O2S.



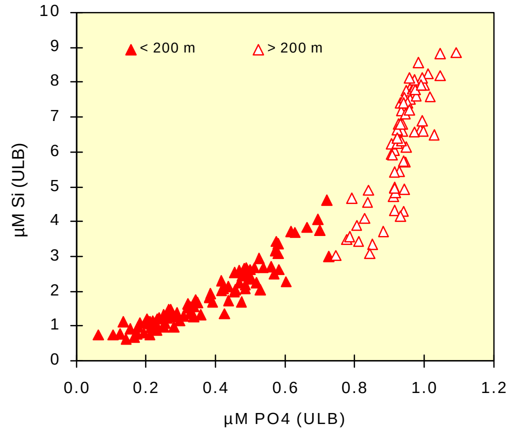


Figure 7. Correlation between nitrate and phosphate for waters taken between 50 and 1200 metres. Nitrate data from Xose Anton Alvarez Salgado, IIM.

Figure 8. Correlation between dissolved silicate and phosphate.

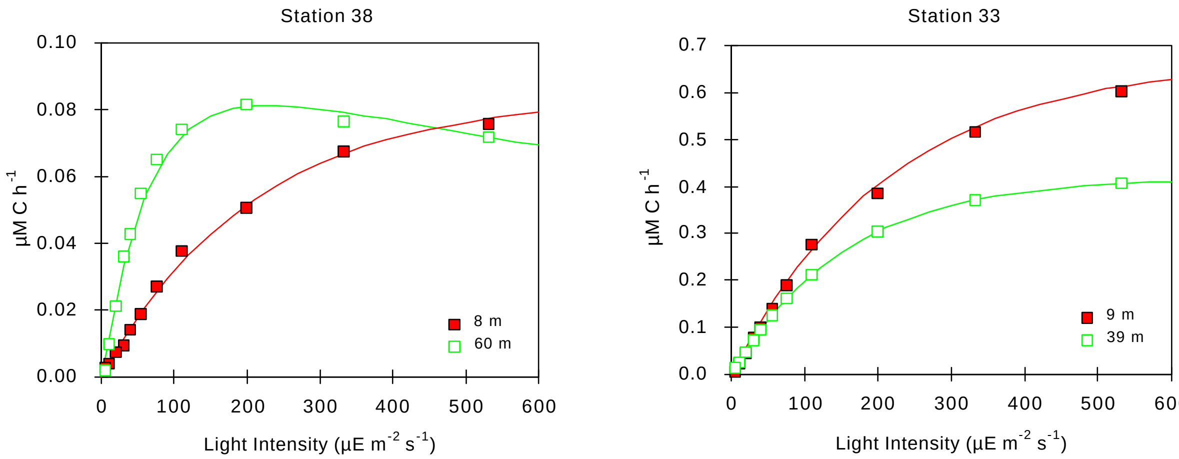
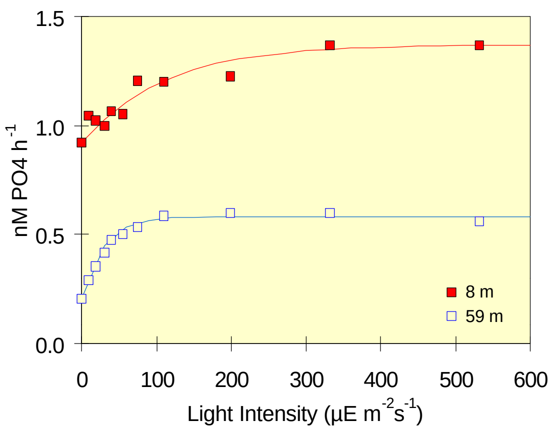


Figure 9. P *vs.* I curves obtained at a shelf station (St. 33) and an offshore station (St. 38) at two depths along the O2N transect.



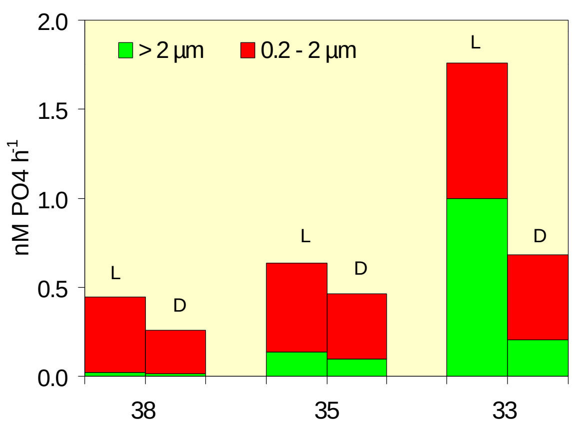


Figure 10. P *vs.* I curves for ^{32}P uptake obtained at two depths for station 2 situated along the O2S transect.

Figure 11. Size-fractionated assimilation of phosphorus measured at 188 µE m^{-2} s^{-1} for stations situated along the O2N transect.

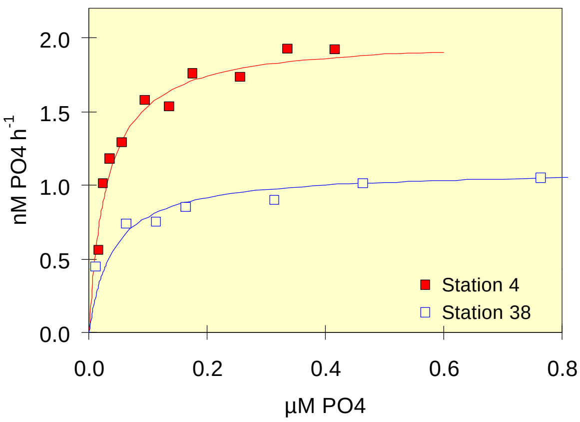


Figure 12. Menten-Michaelis kinetics of phosphorus assimilation conducted at 188 µE m^{-2} s^{-1}.

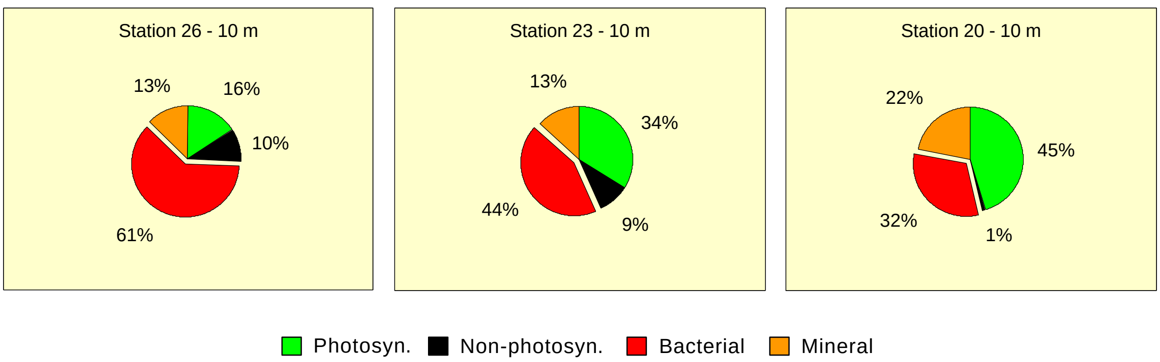


Figure 13. Relative phosphorus assimilation by various fractions.

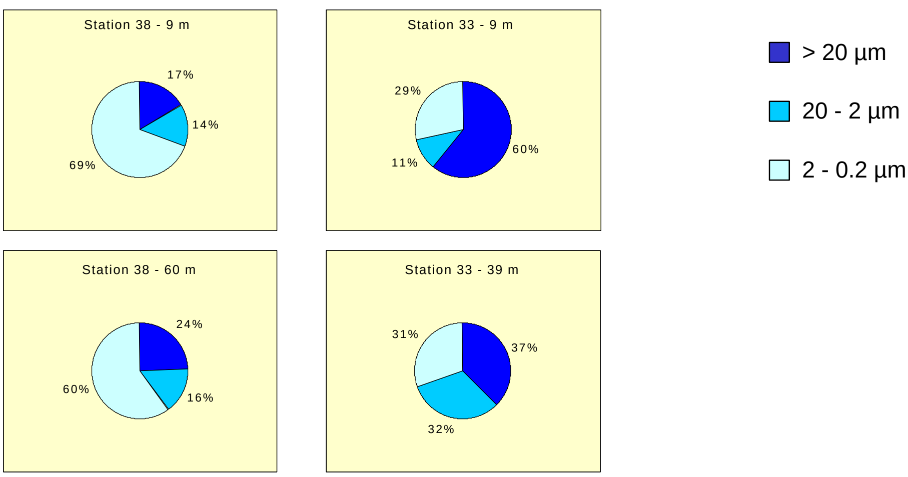


Figure 14. Size-fractionated production measured at 188 µE m^{-2} s^{-1} at a shelf station (St. 33) and an offshore station (St. 38) along the O2N transect.

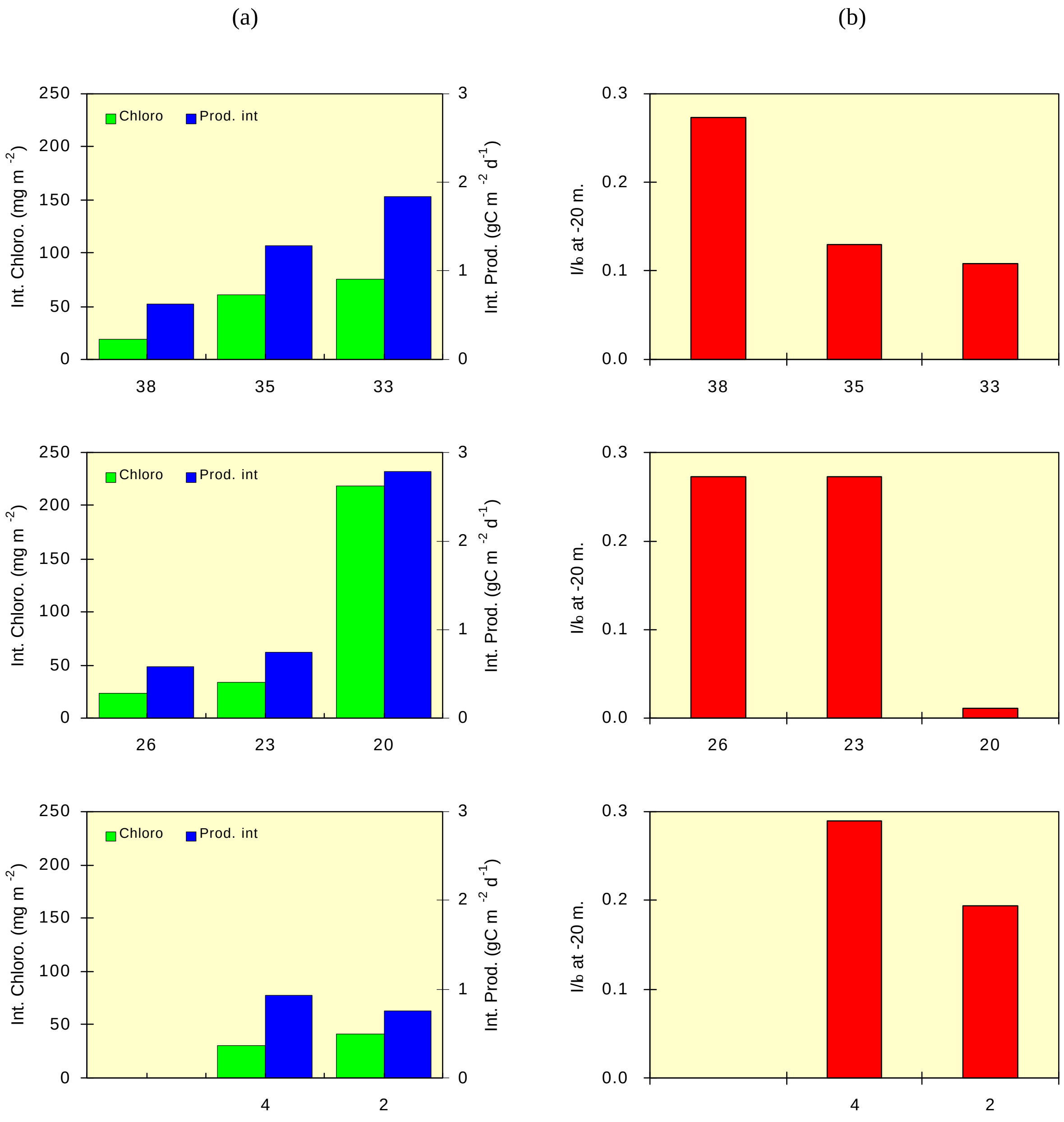


Figure 15. (a) Integrated primary production and chlorophyll *a* concentrations, and (b) relative light penetration at 20 m depth along the O2N, O2P and O2S transects.

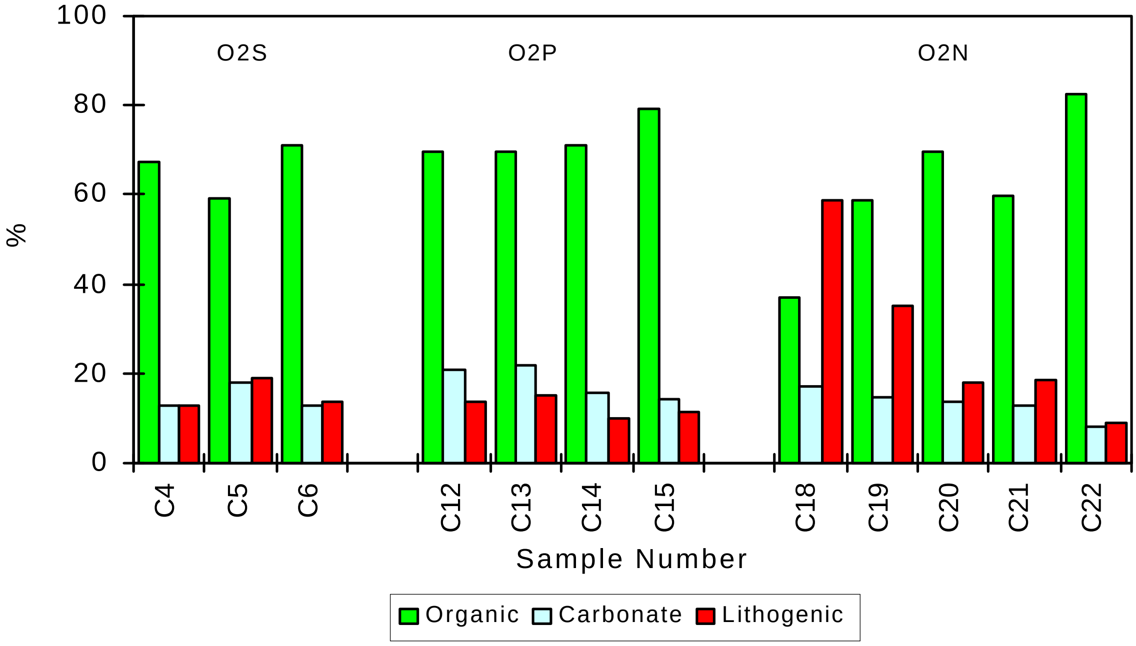


Figure 16. Composition of organic, carbonate and lithogenic components in surface suspended matter collected during the *Belgica BG9714C* cruise (20 June - 2 July 1997).

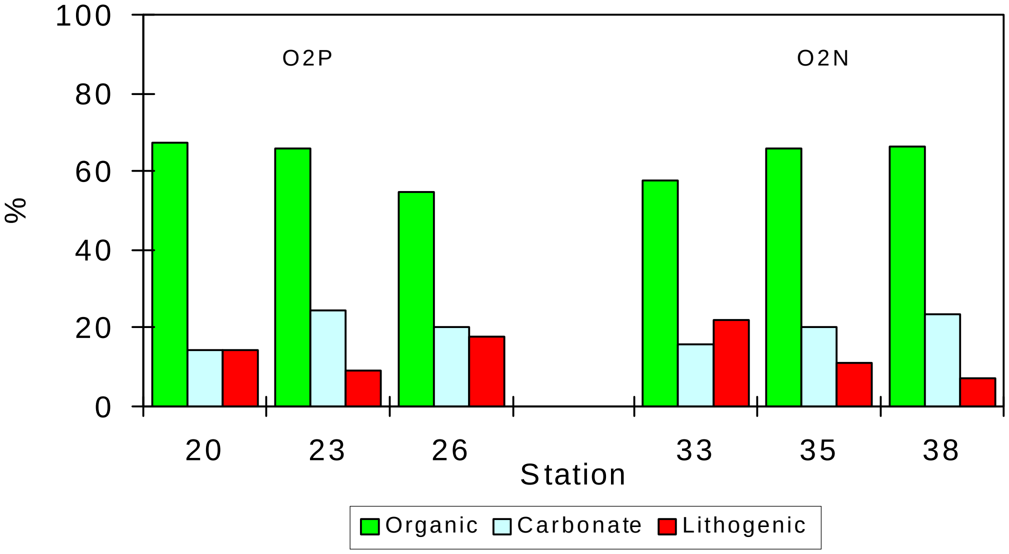


Figure 17. Composition of organic, carbonate and lithogenic components in surface suspended matter collected during the *Belgica BG9815C* cruise (27 June - 7 July 1998).

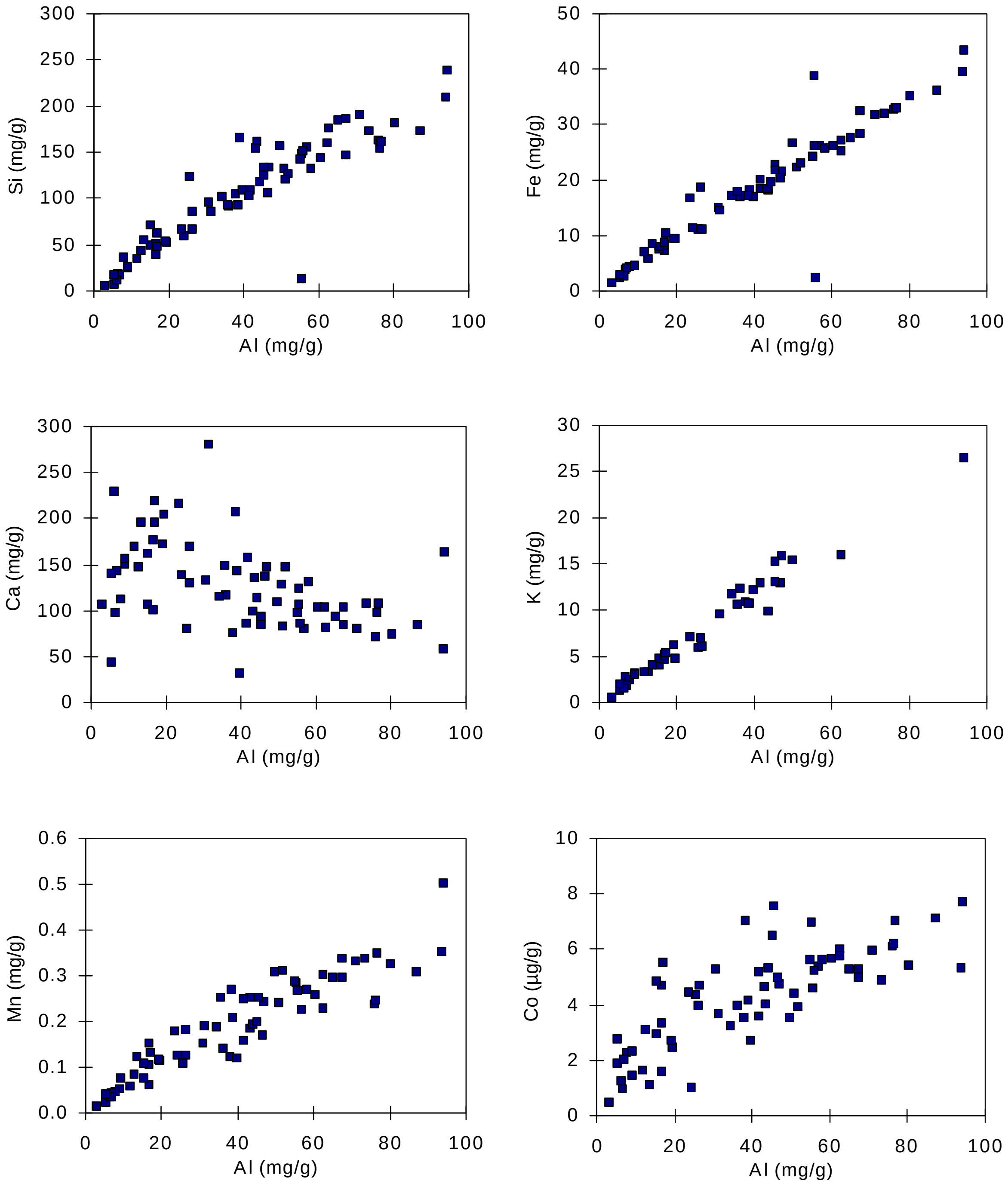


Figure 18. Elemental composition as a function of aluminium in particulate matter collected by sediment traps during the period from July 1997 to February 1998.

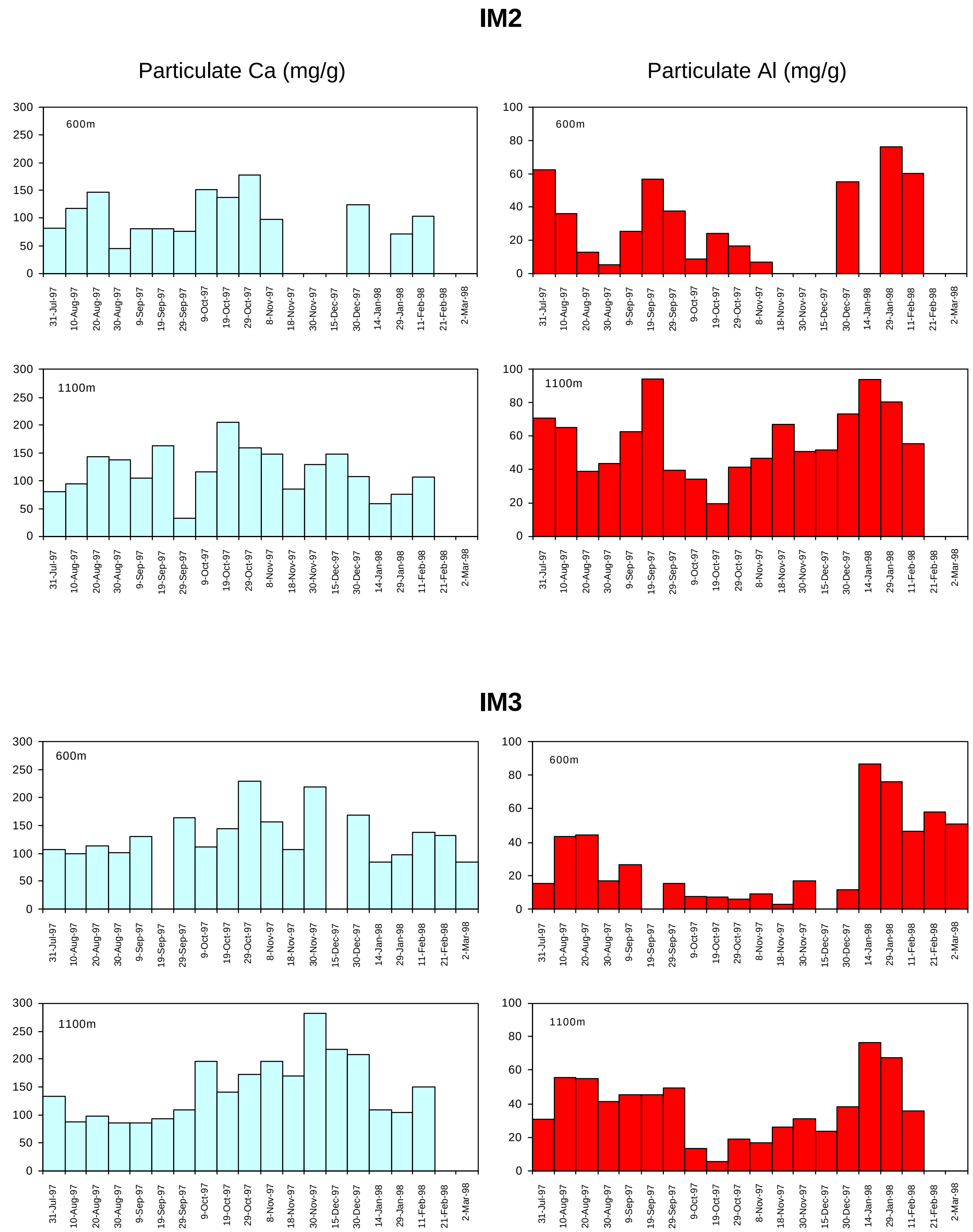


Figure 19. Particulate Ca and Al contents in the suspended matter collected by sediment traps during the period of July 1997 to February 1998..