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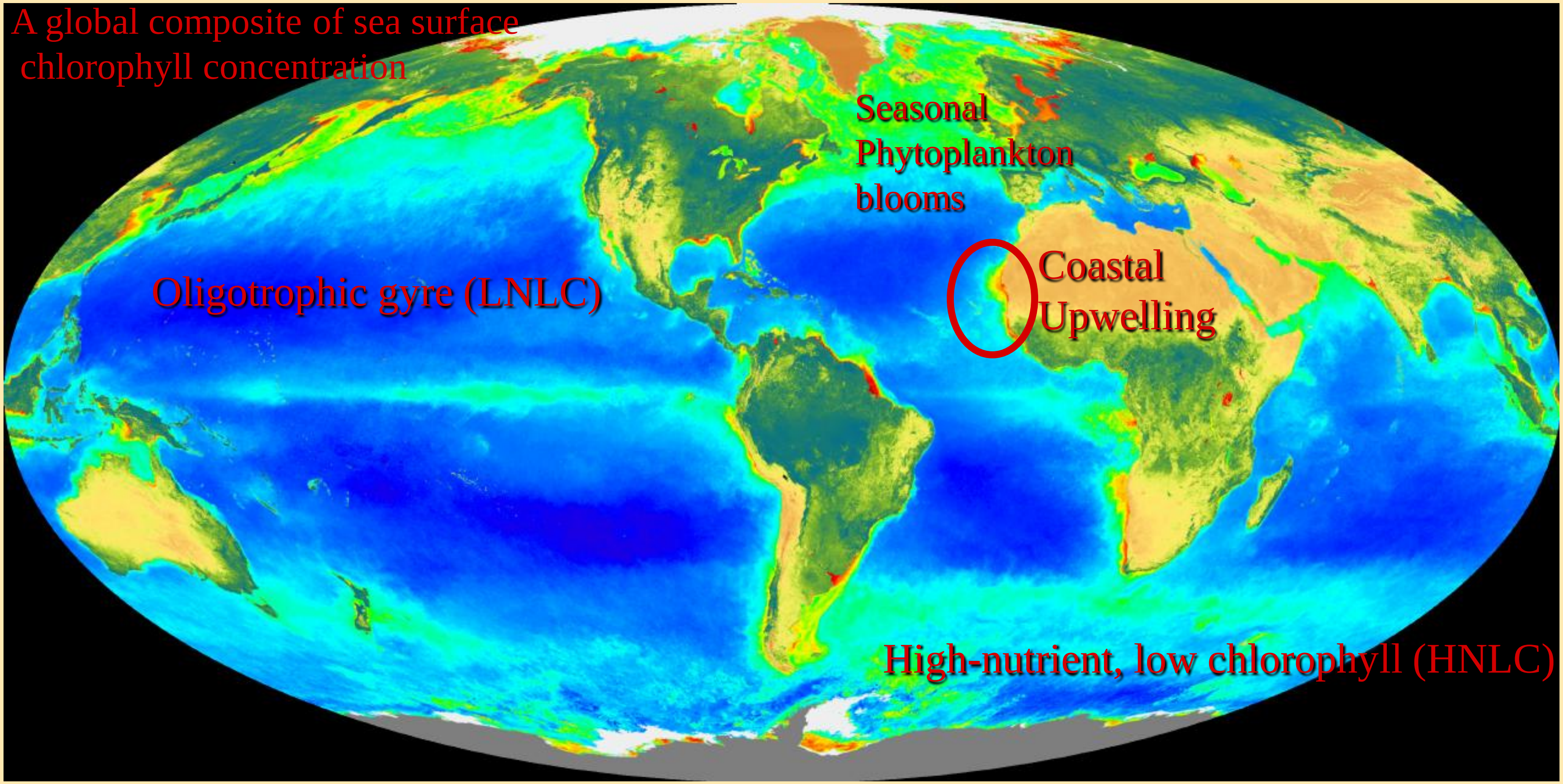
Primary Production in the Ocean



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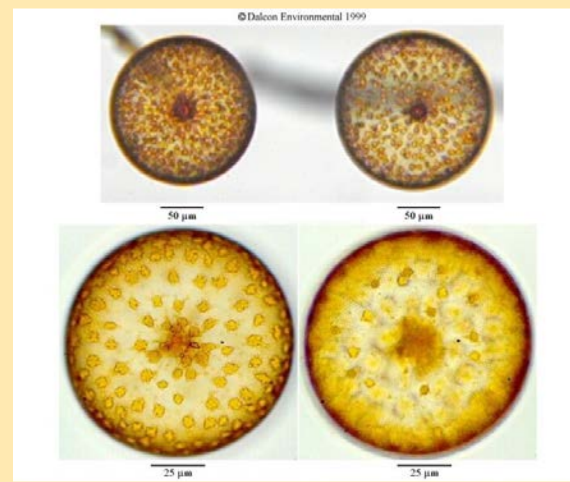
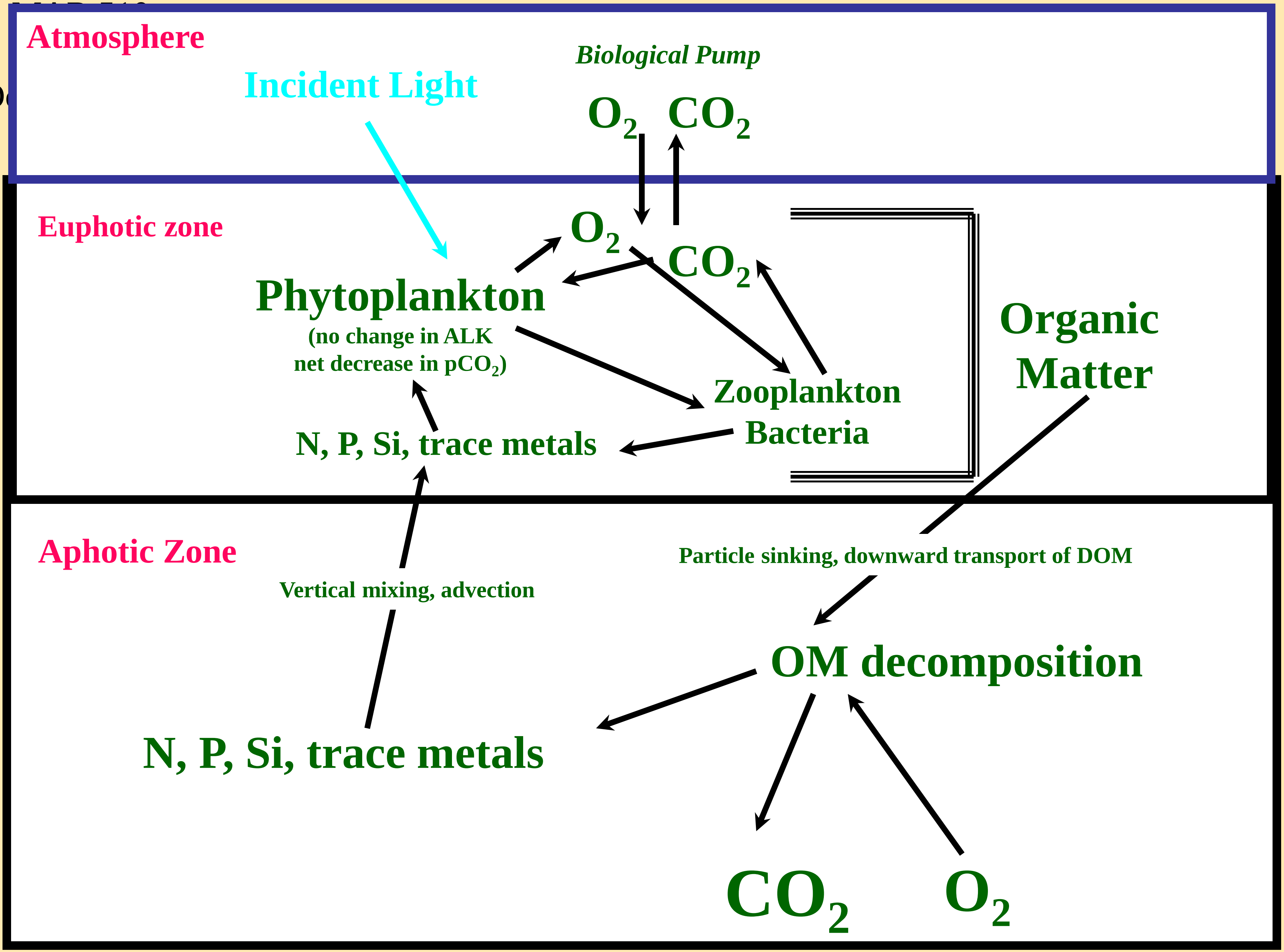
Primary production

Examples of the larger phytoplankton



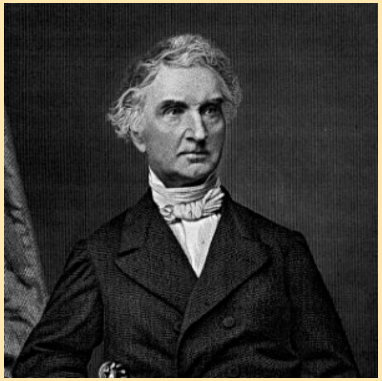
Diatom



Atmosphere
Biological Pump
Incident Light
O_2
CO_2
Euphotic zone
O_2
CO_2
Phytoplankton
(no change in ALK
net decrease in pCO_2)
Organic
Matter
Zooplankton
Bacteria
N, P, Si, trace metals
Aphotic Zone
Particle sinking, downward transport of DOM
Vertical mixing, advection
OM decomposition
N, P, Si, trace metals
CO_2
O_2

Law of the Minimum - Liebig's Law

Justus von Liebig, generally credited as the "father of the fertilizer industry", formulated the law of the minimum: if one crop nutrient is missing or deficient, plant growth will be poor, even if the other elements are abundant. Liebig likens the potential of a crop to a barrel with staves of unequal length. The capacity of this barrel is limited by the length of the shortest stave (in this case, phosphorus) and can only be increased by lengthening that stave. When that stave is lengthened, another one becomes the limiting factor.



1803-1873

For Phytoplankton

1) Light
2) Macronutrients (N, P)
3) Micronutrients (Fe, Zn)

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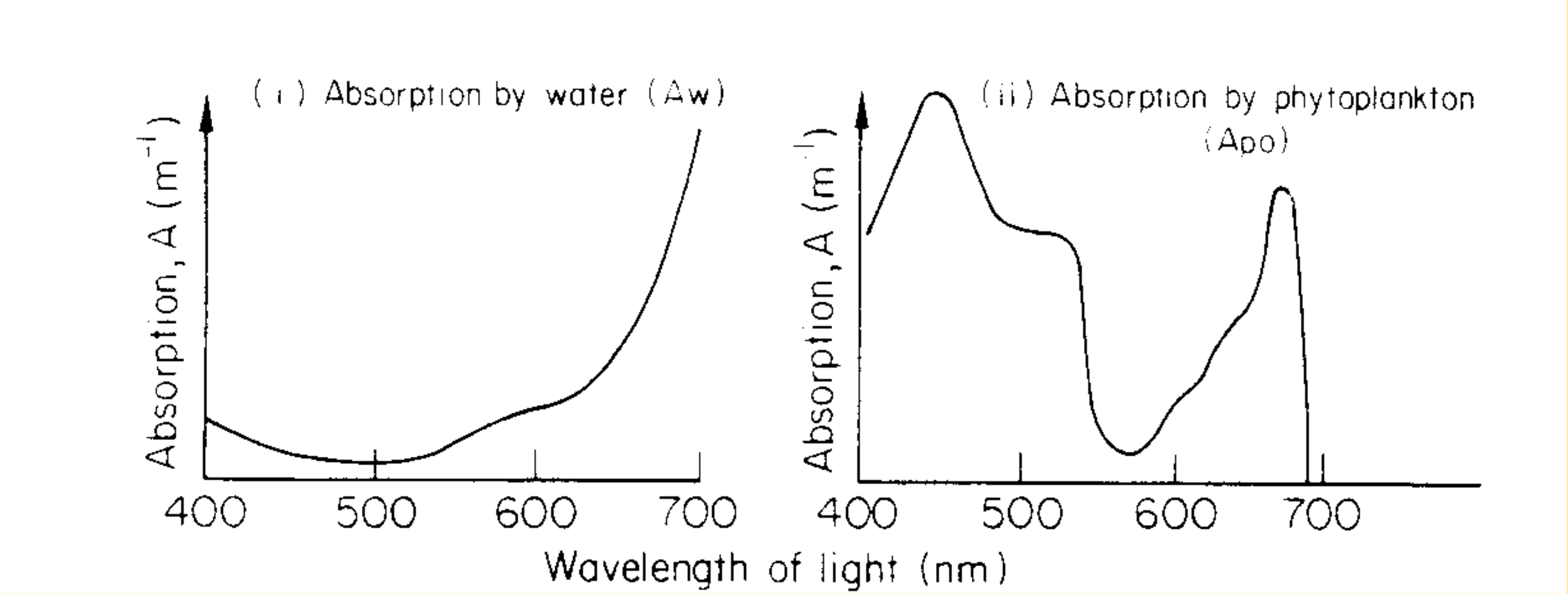
Behavior of Light in the Sea

1)Exponential decrease in intensity with depth (z)

$$I_z = I_0 \times e^{-kz}$$

2) Preferential absorption in the ‘red-end’ of the spectrum



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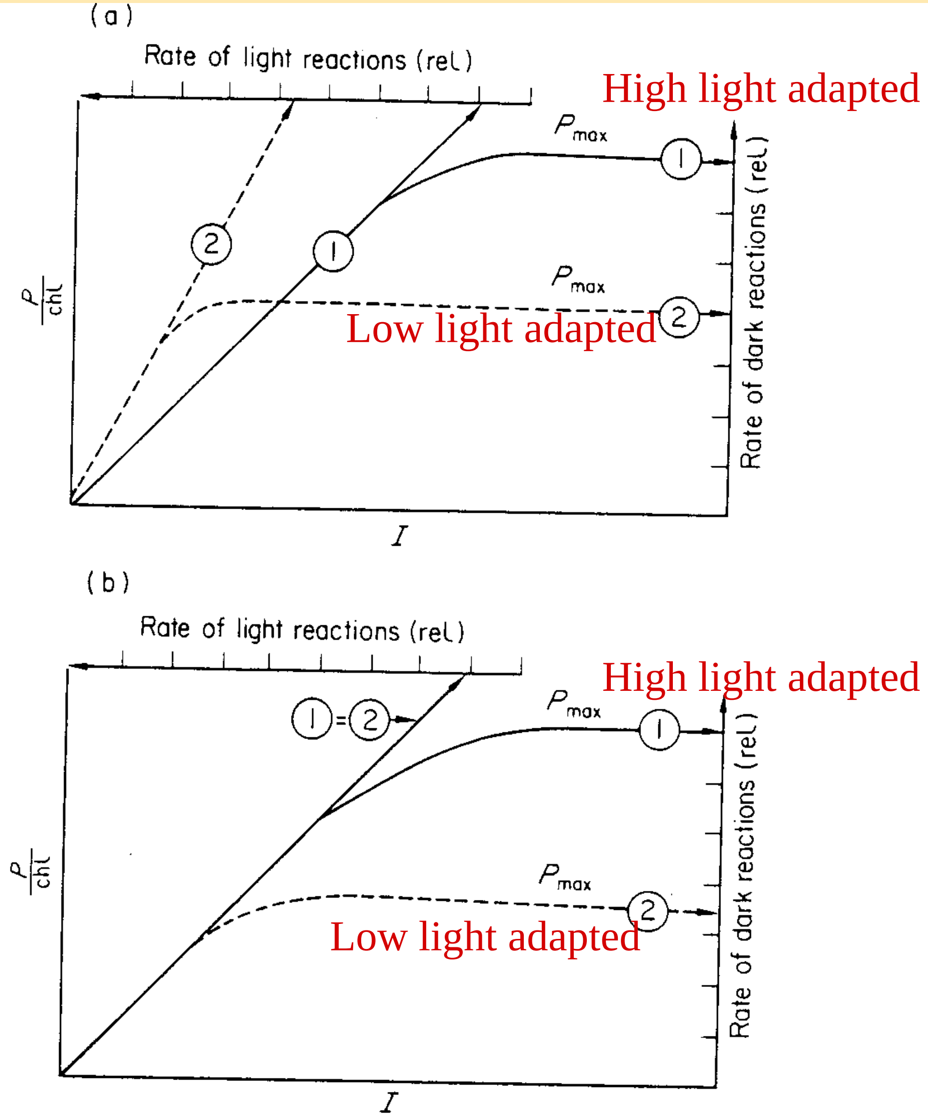
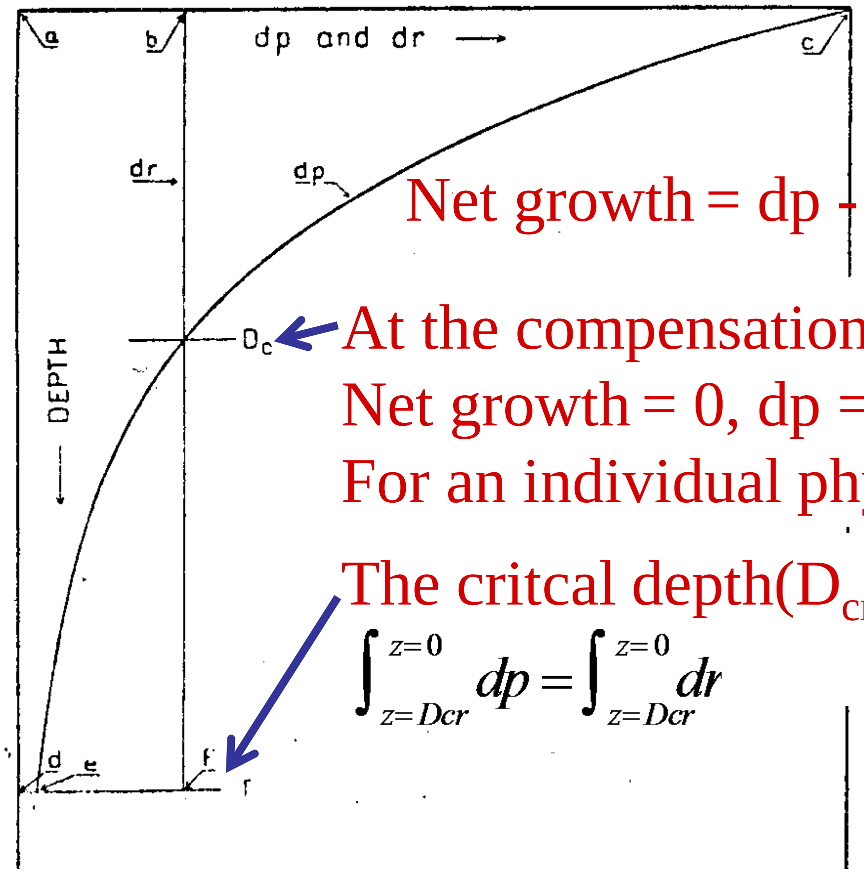


Fig. 3.12. The effects of high and low light conditions on photosynthetic responses in phytoplankton. Population (1) is located at the top of the euphotic zone, population (2) at the bottom. Situation (a) reflects the response of increased chlorophyll content of population (2), that is, the light reaction rate is higher in (2) than (1). Situation (b) reflects the response of the light reactions being equal.

$$P = P_{max} \times I/(I+k_I)$$

Sverdrup (1952)



Net growth = dp - dr

At the compensation depth (D_c)
Net growth = 0, dp = dr
For an individual phytoplankton cell

The critcal depth(D_{cr}) is defined such that

$$\int_{z=Dcr}^{z=0} dp = \int_{z=Dcr}^{z=0} dr$$

Figure 1. Schematic representation of the variation with depth of the increase of organic matter by photosynthesis, *dp*, and the decrease by respiration, *dr*. Increase and decrease apply to unit volume and unit time.

When the mixed layer depth (mld) < D_{cr}

$\int_{z=mld}^{z=0} dp > \int_{z=mld}^{z=0} dr$, a phyto plankton bloom can occur

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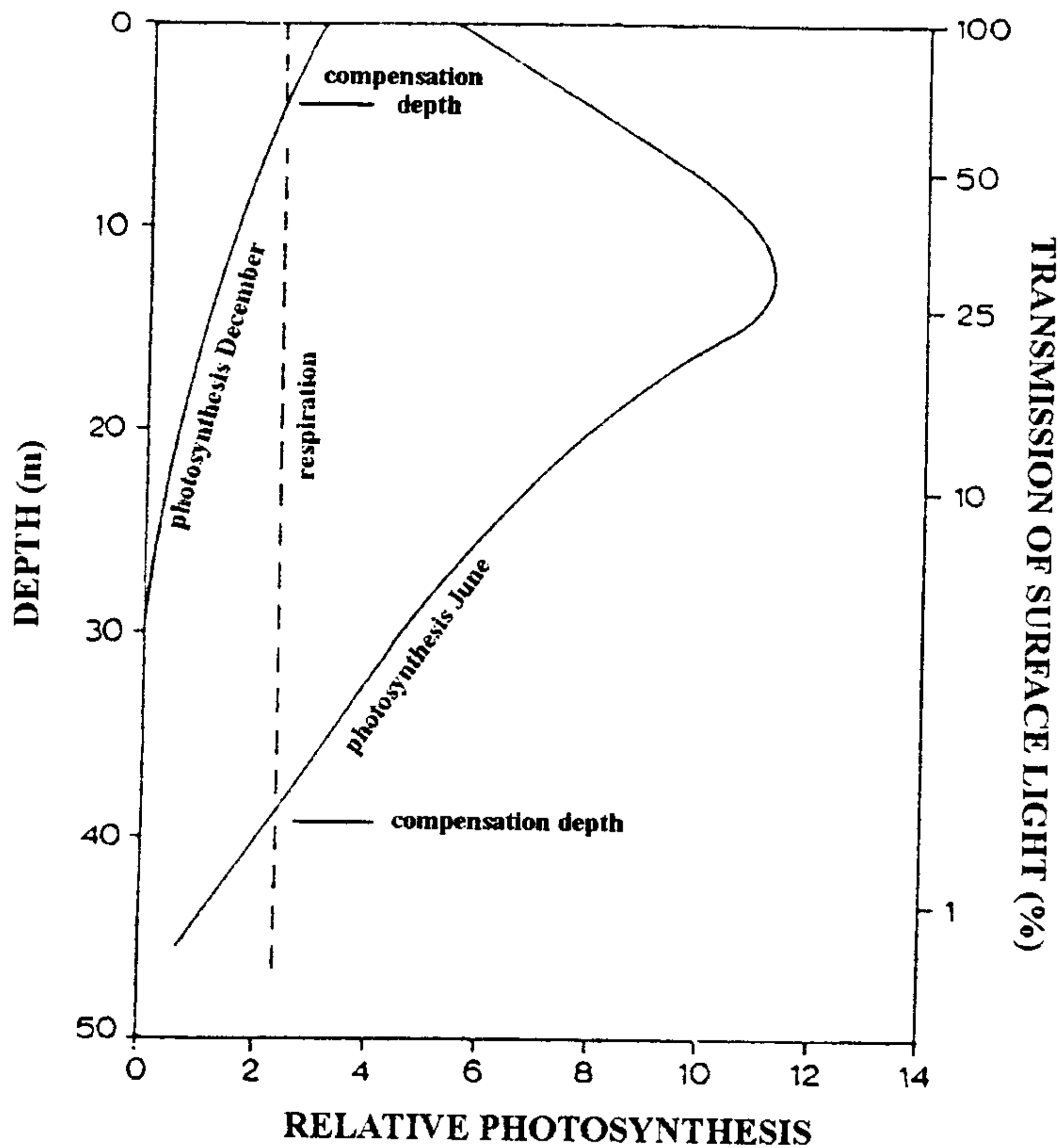

FIGURE 9.7. Integrated daily rate of primary productivity as a function of depth.

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Ch
Ocea

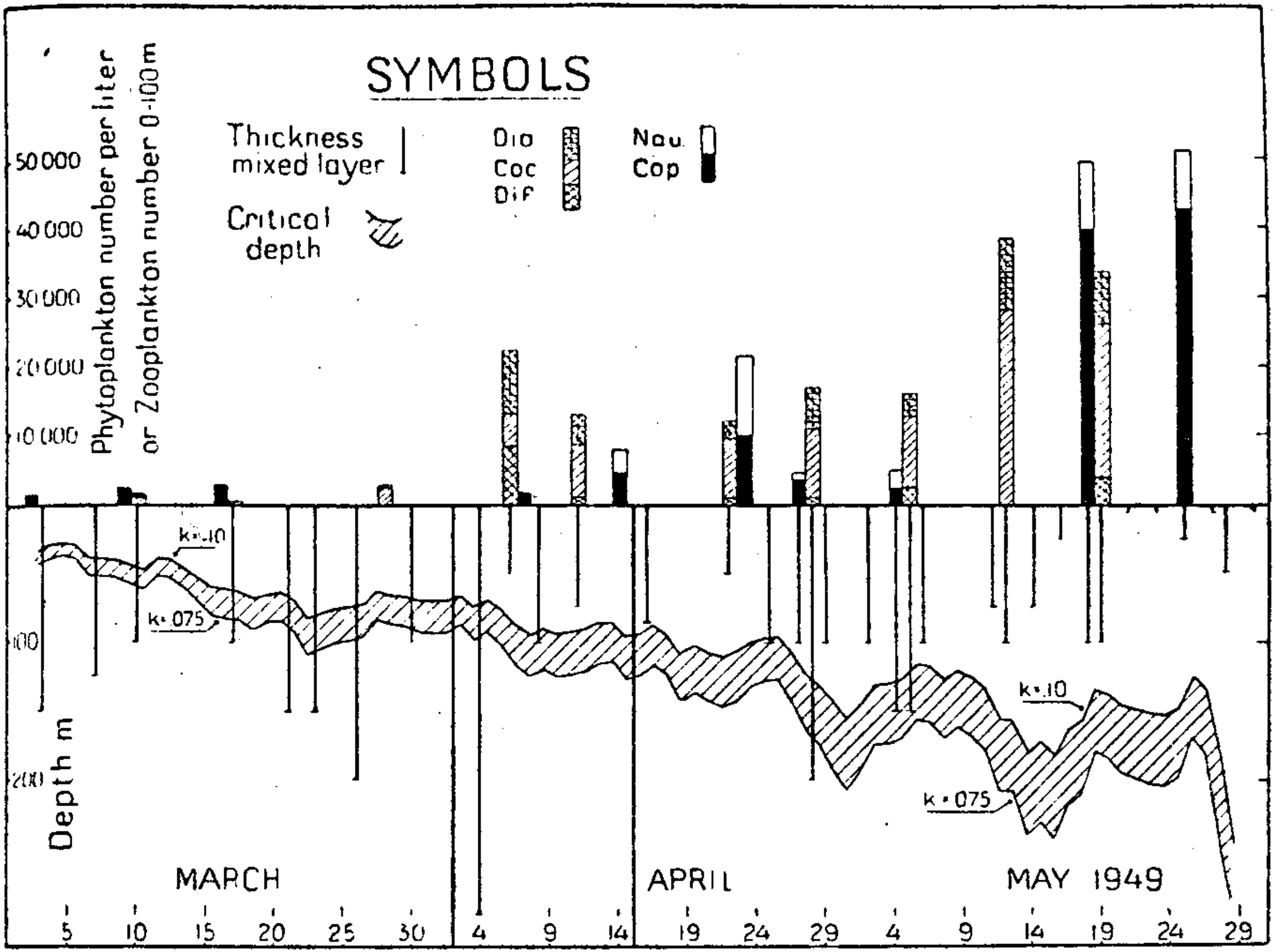

Figure 2. Results of observations at Weather Ship "M" (66°N., 2°E. Gr.). The symbols are explained in the graph, where the following abbreviations have been used:— Dia, Diatomaceae; Coc, Coccolithophoridae; Dif, Dinoflagellatae; Nau, Nauplii; and Cop, Copepods.

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Onset of nutrient limitation

Onset of light limitation

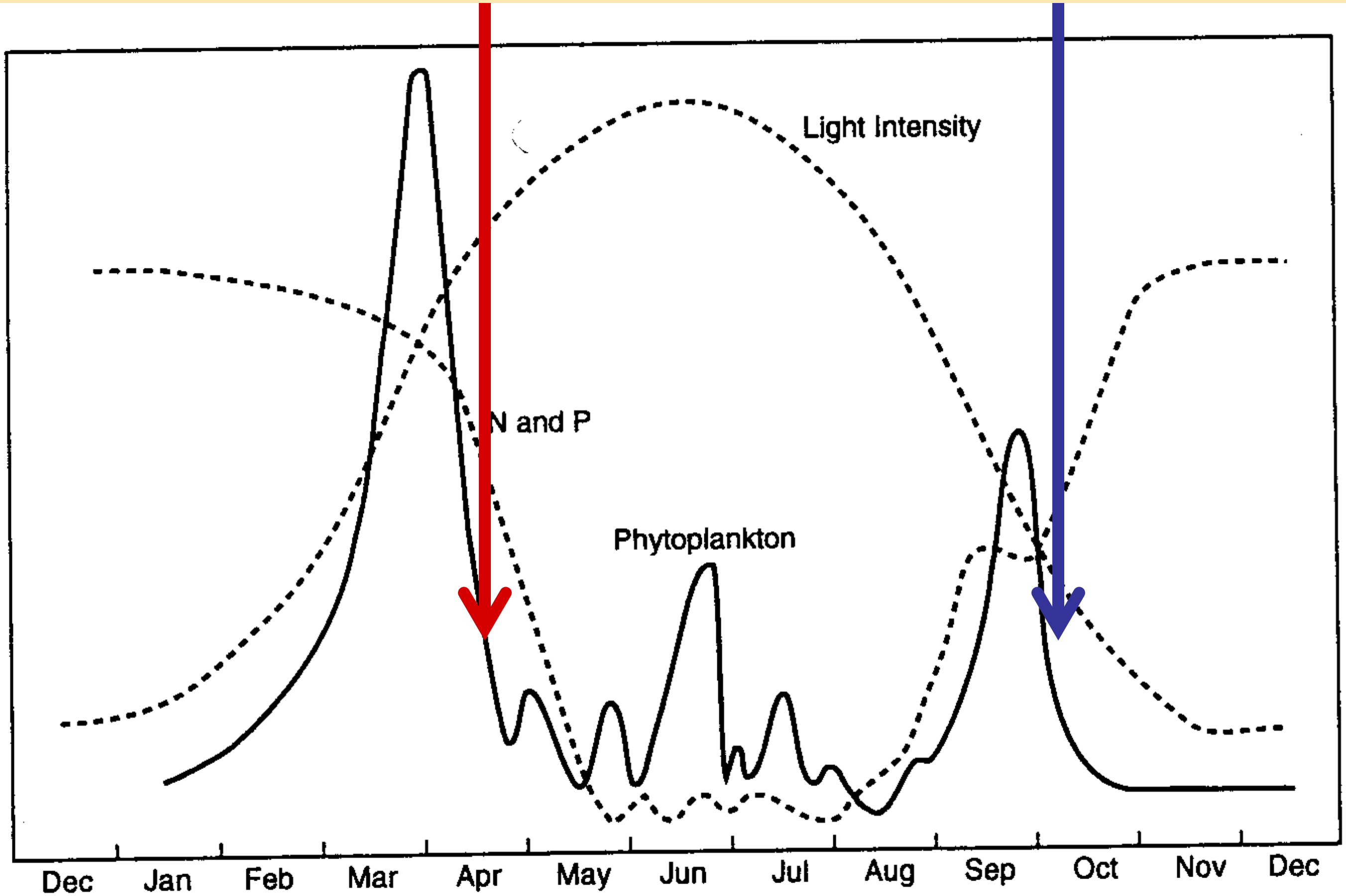

FIGURE 9.6. Seasonal variation of phytoplankton, nutrients, and light in a typical northern temperate sea.

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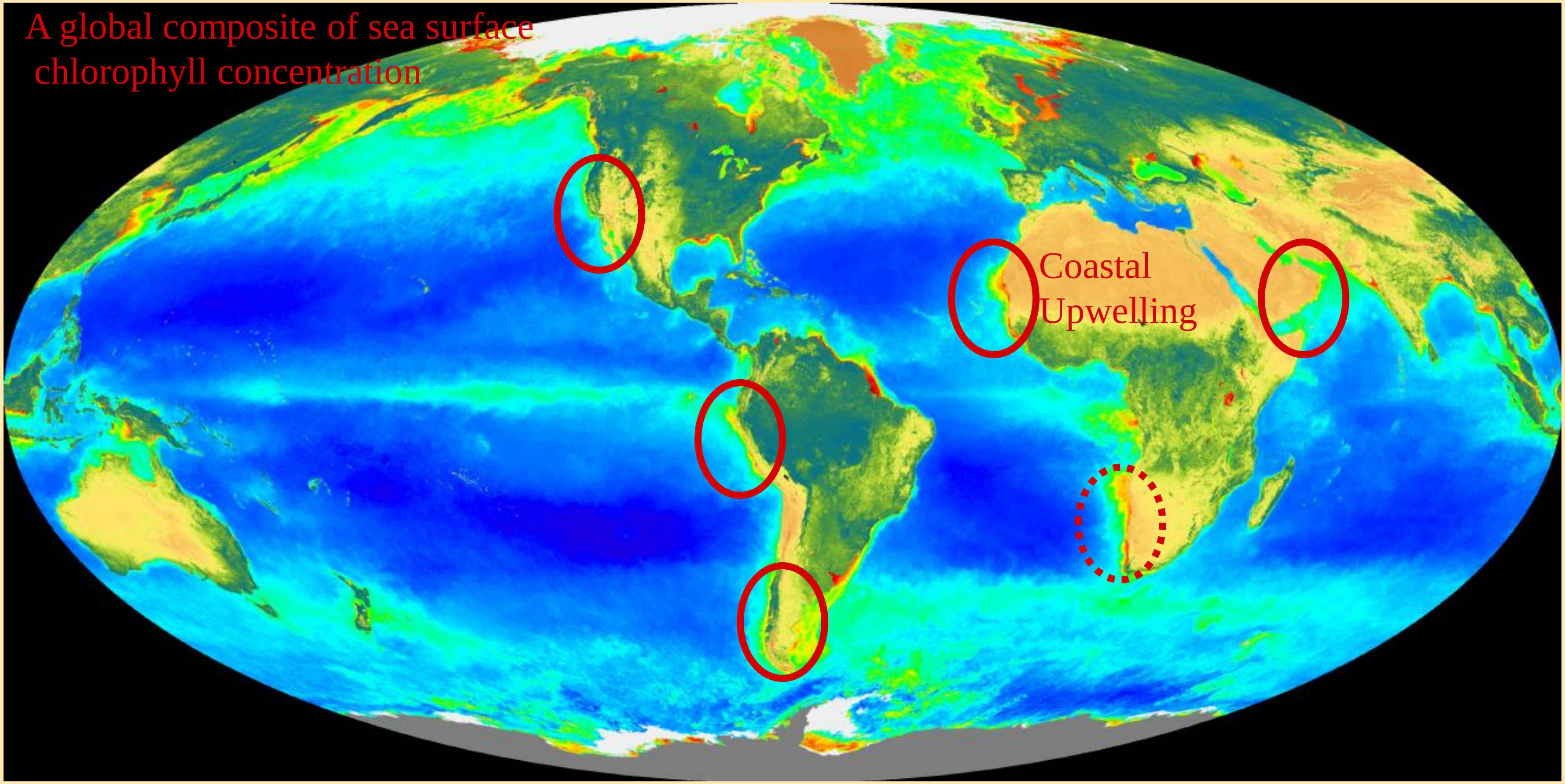
Major Coastal Upwelling Zones



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Primary production

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Herbland &
Le Bouteiller
(1981)
J. Plank. Res.

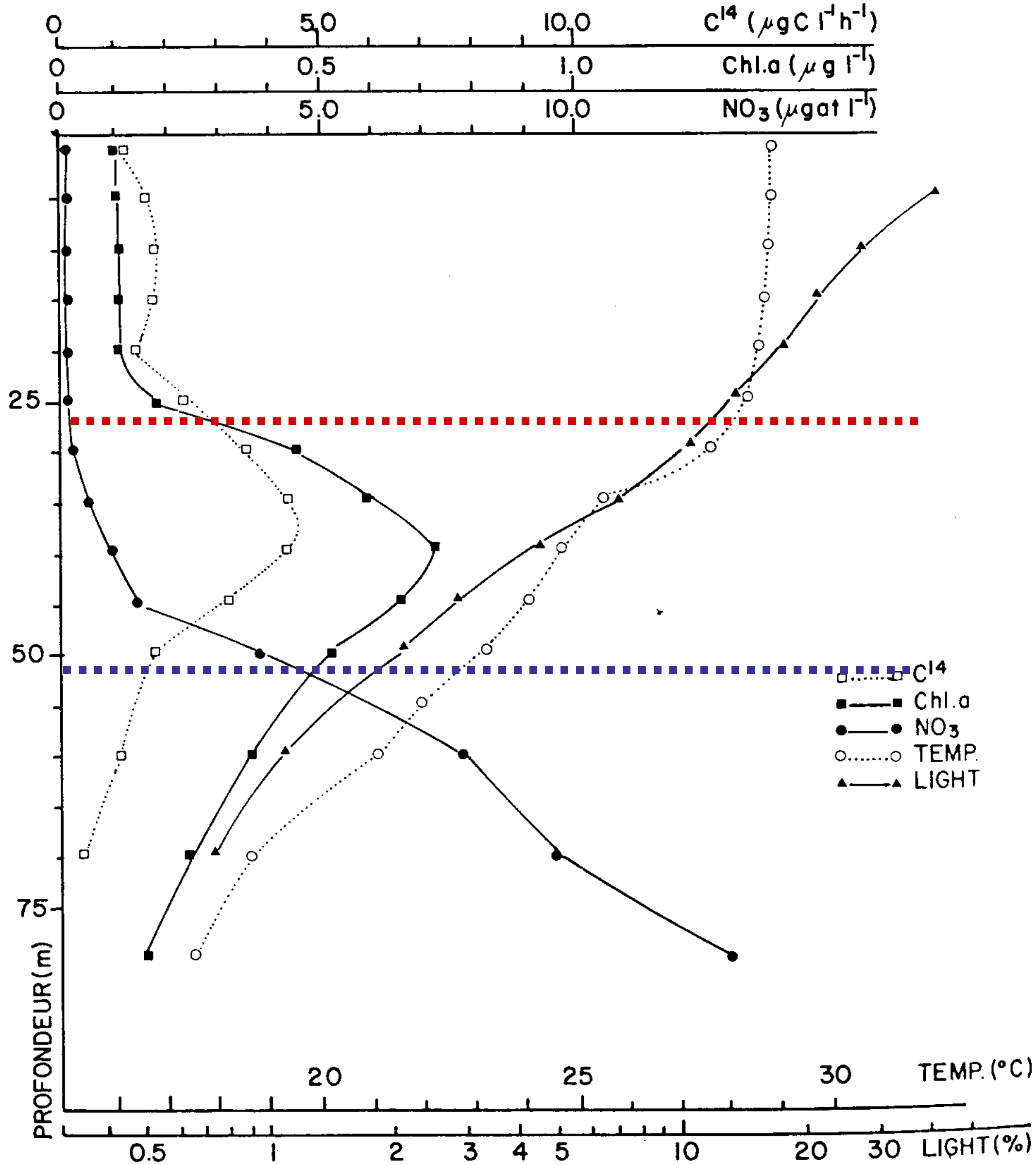

Fig. 2. The mean profiles of temperature, light, nitrate, chlorophyll *a* and $^{14}CO_2$ uptake during a long duration station (14 days) in the Equatorial Atlantic Ocean (0°-4° W). Cruise SOP 1.

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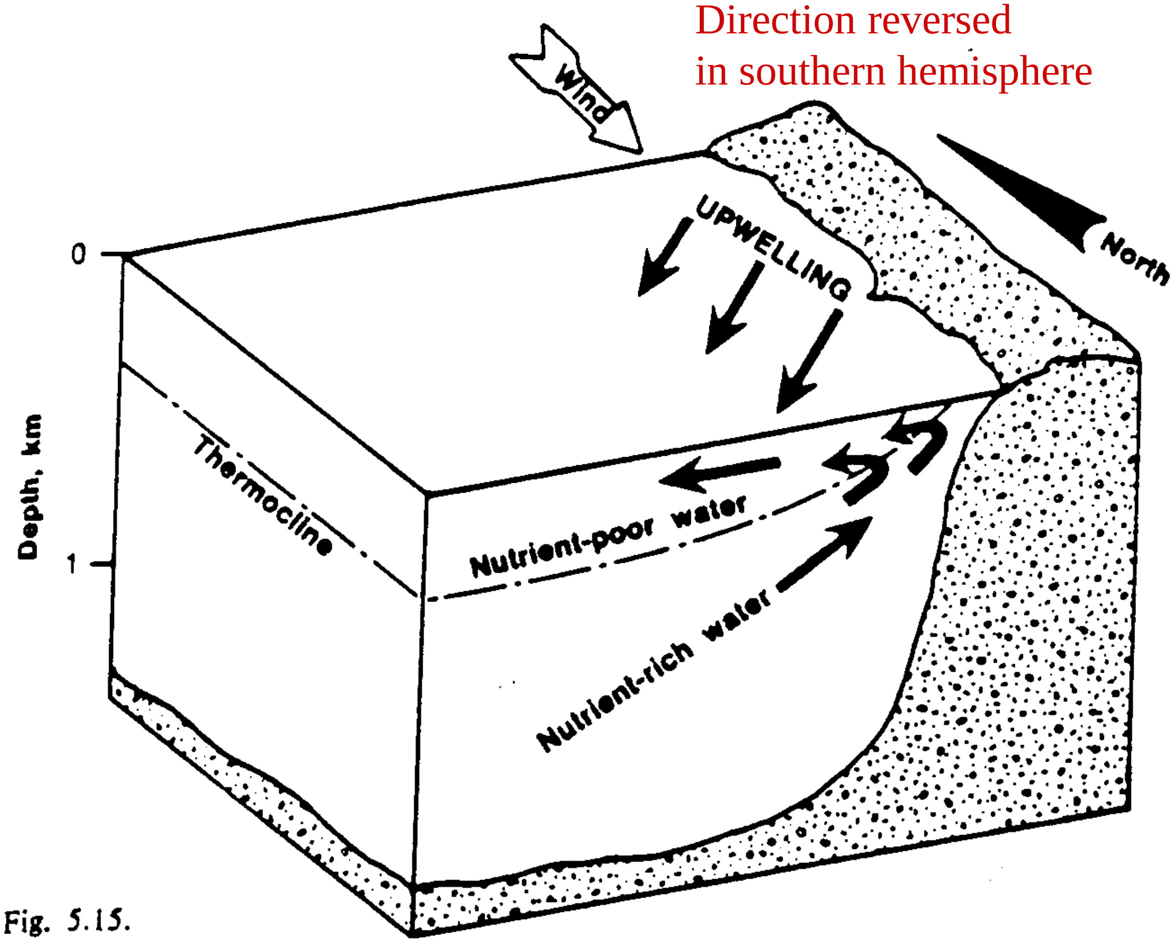

Fig. 5.15.

Primary production

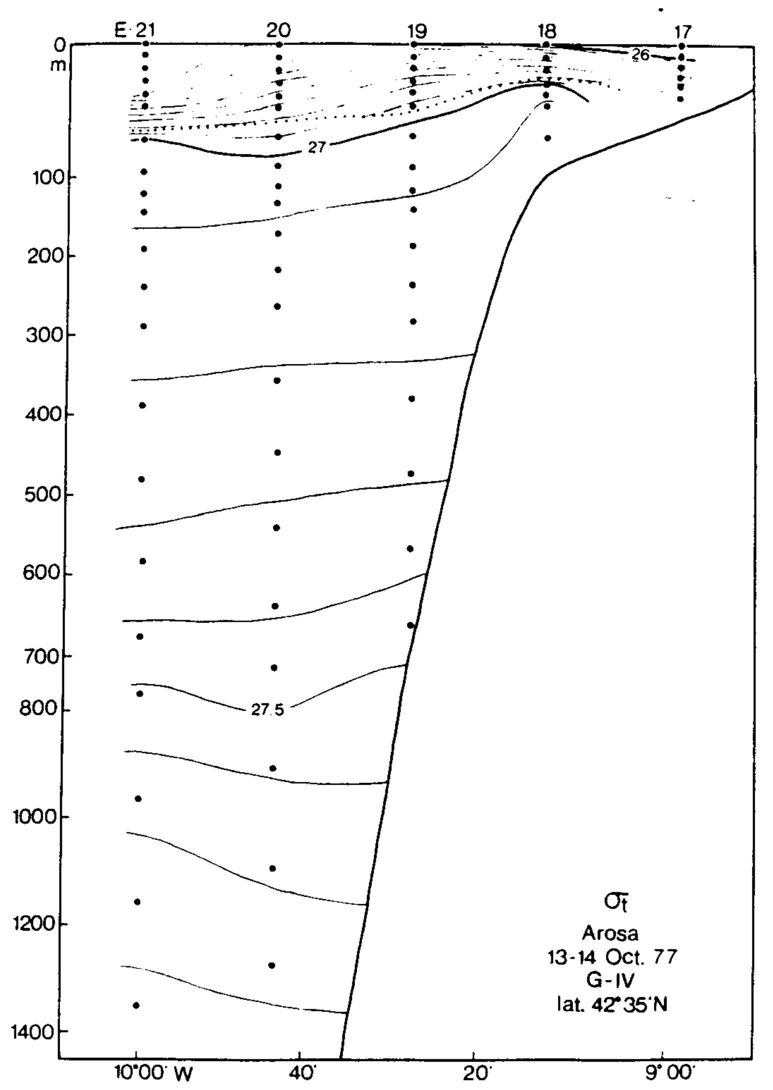

Fig. 10. Vertical distribution of density off Ría of Arosa at latitude 42°33'N, in October. "Galicia IV" cruise.

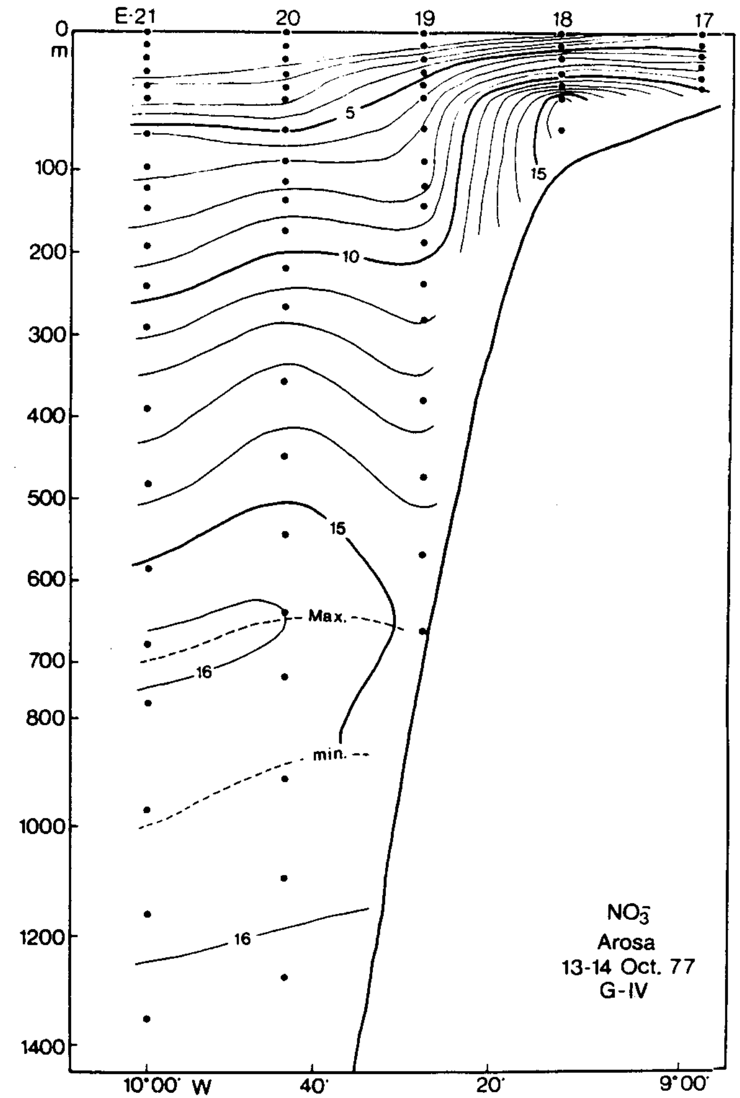

Fig. 11. Vertical distribution of nitrate along the same section shown in Fig. 10.

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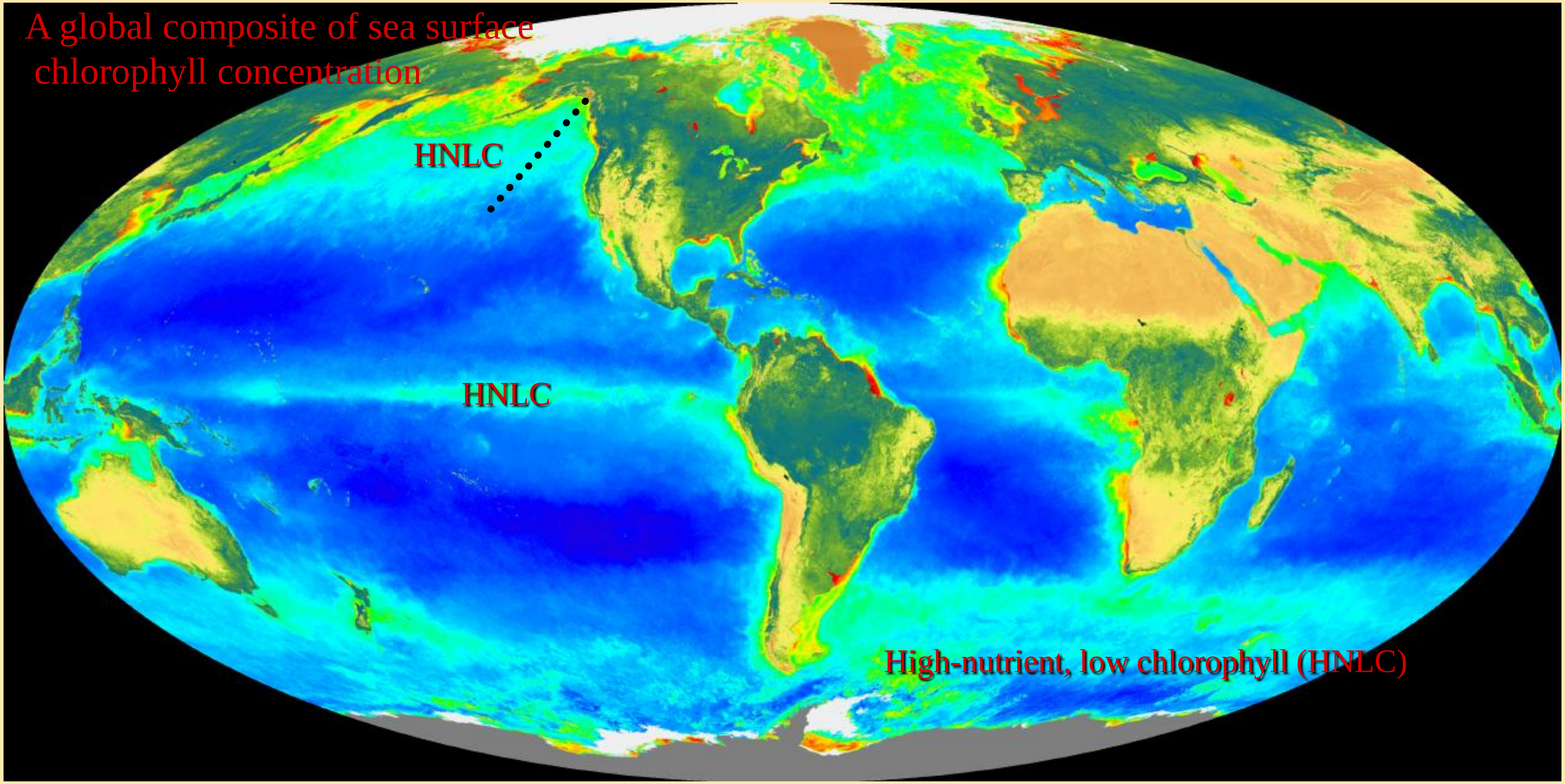
Martin et al. Fe studies in subarctic N. Pacific



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Primary production

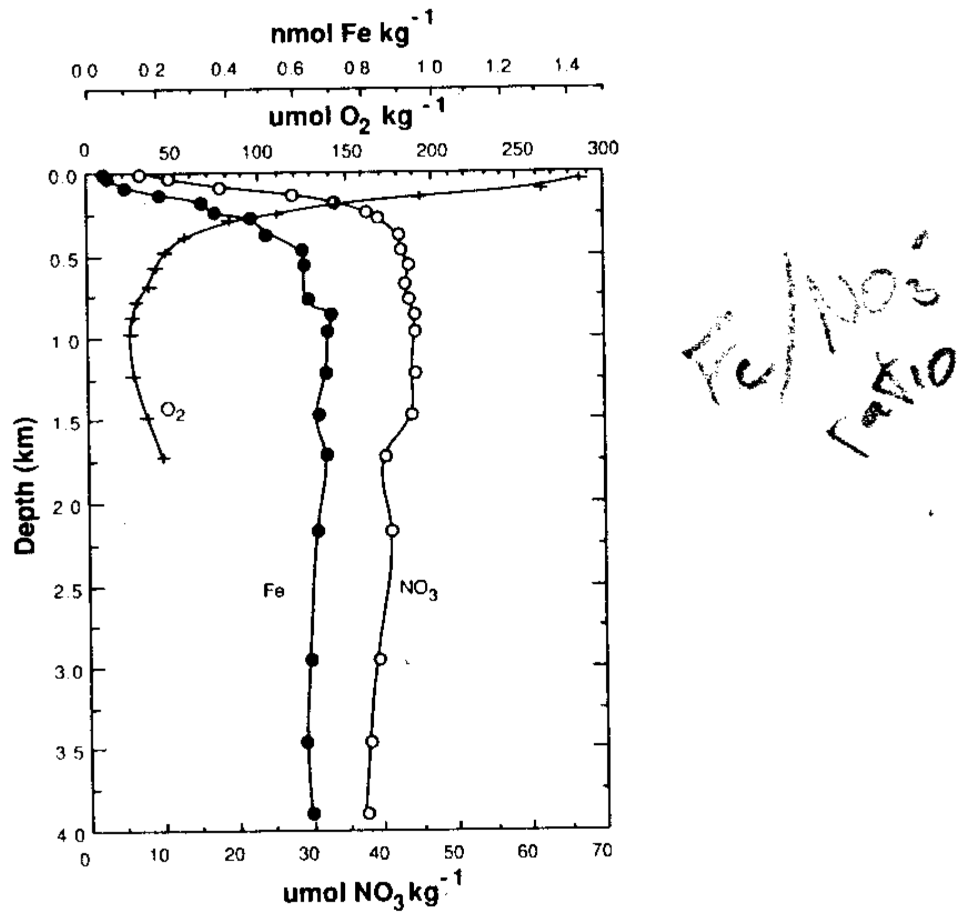

Fig. 4. Vertical distribution of dissolved Fe at Sta. T-7 ("Papa") together with oxygen and nitrate; data from Appendix Table A4.

Martin et al. (1989) Deep-Sea Res.

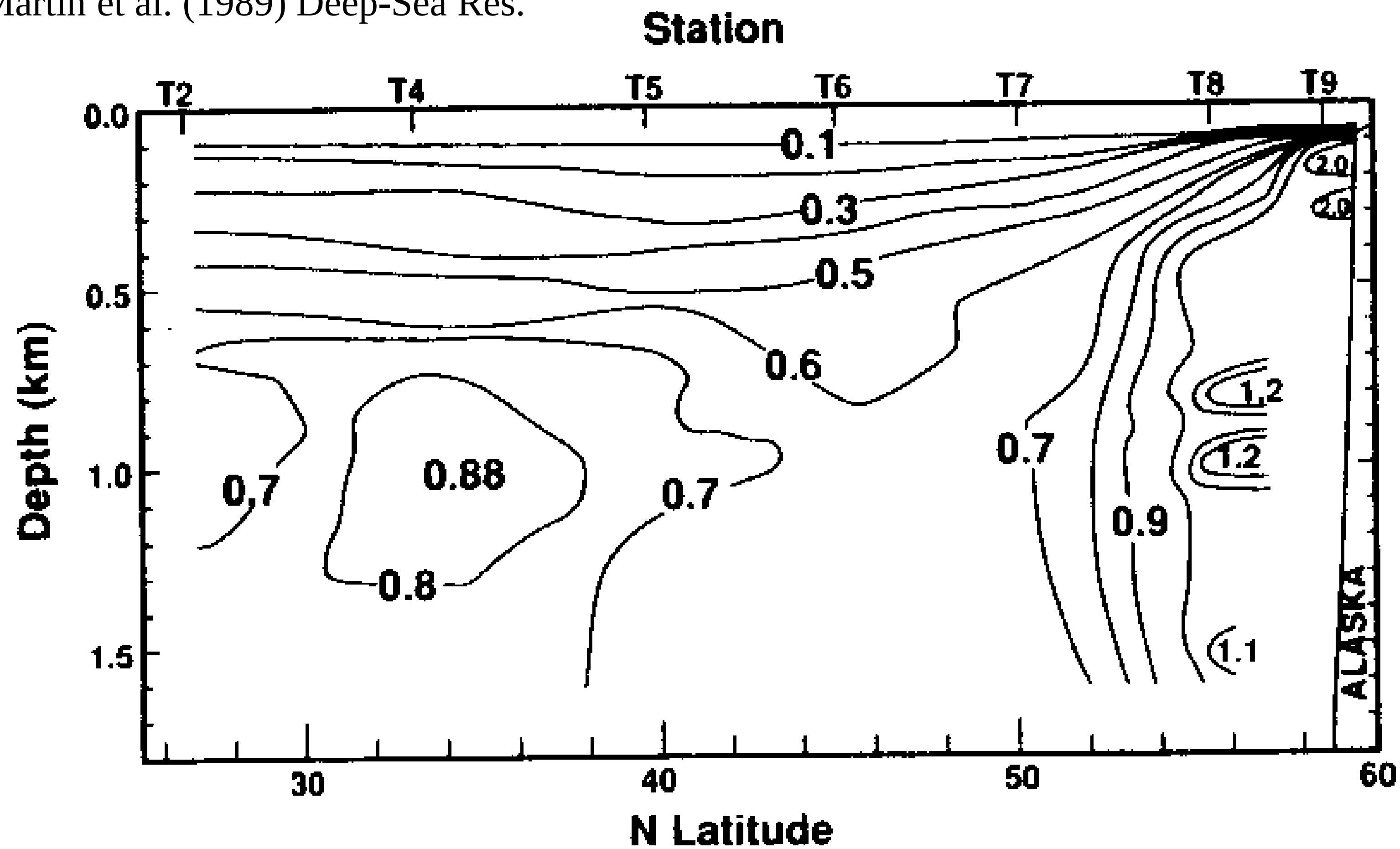

Fig. 7. A dissolved Fe section; station locations are shown in Fig. 1.

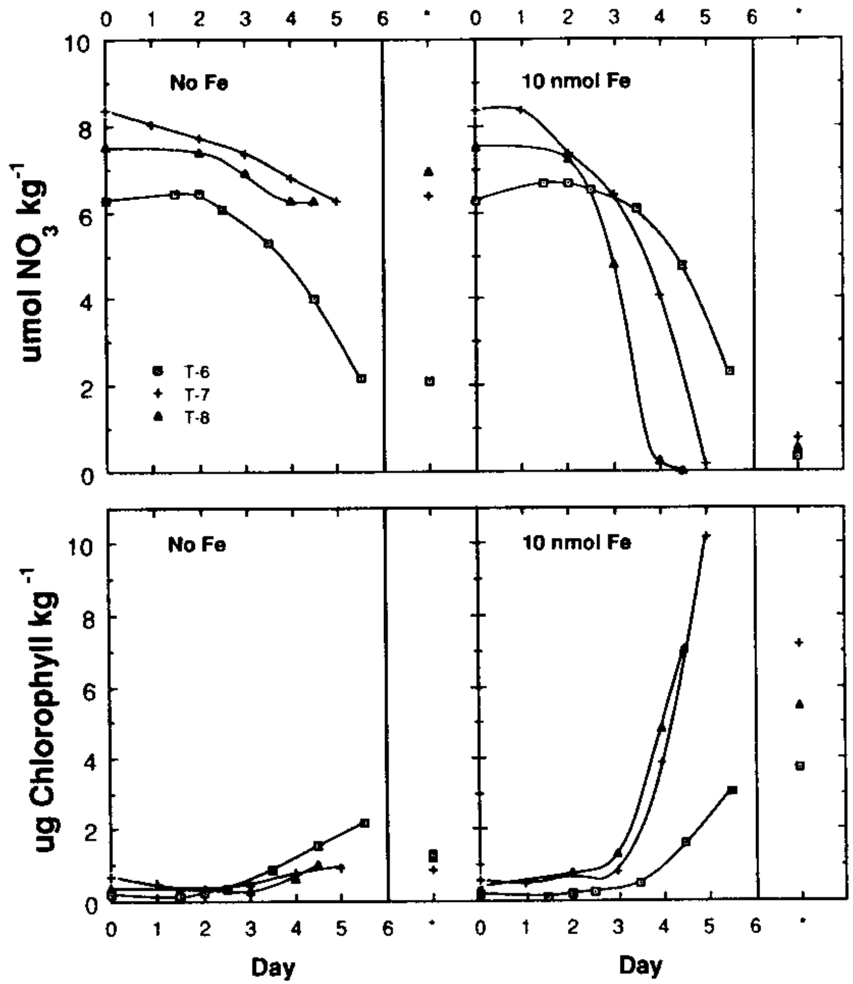

Fig. 12. Chlorophyll and NO_3 levels vs experimental day at Stas T-6, T-7 and T-8. Data for second sets of replicates measured only at the end of the experiment are in the boxes marked with an *. Stas T-6 and T-7 data are not shown for day 6 since growth had stopped, as evidenced by decreases in chlorophyll levels (Appendix Tables A8 and A9).

Primary production

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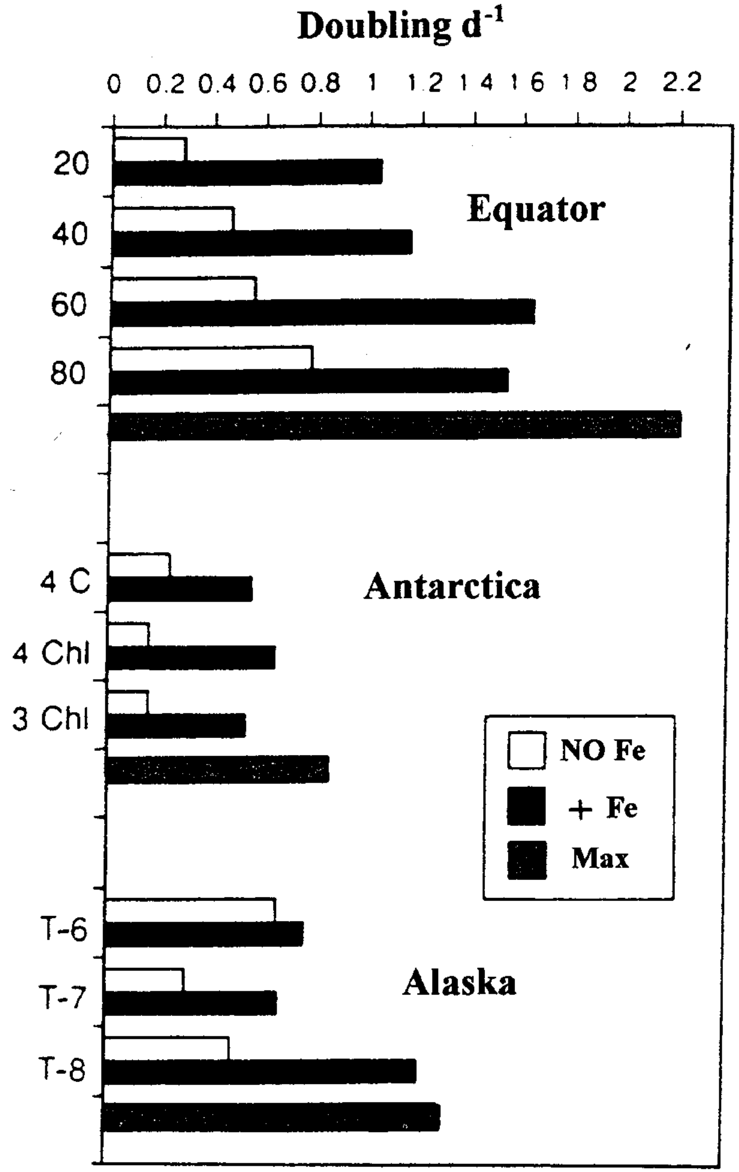

FIGURE 9.16. The effect of the additions of Fe on the doubling times of the growth of phytoplankton in the North Pacific, Equatorial Pacific, and South Pacific.

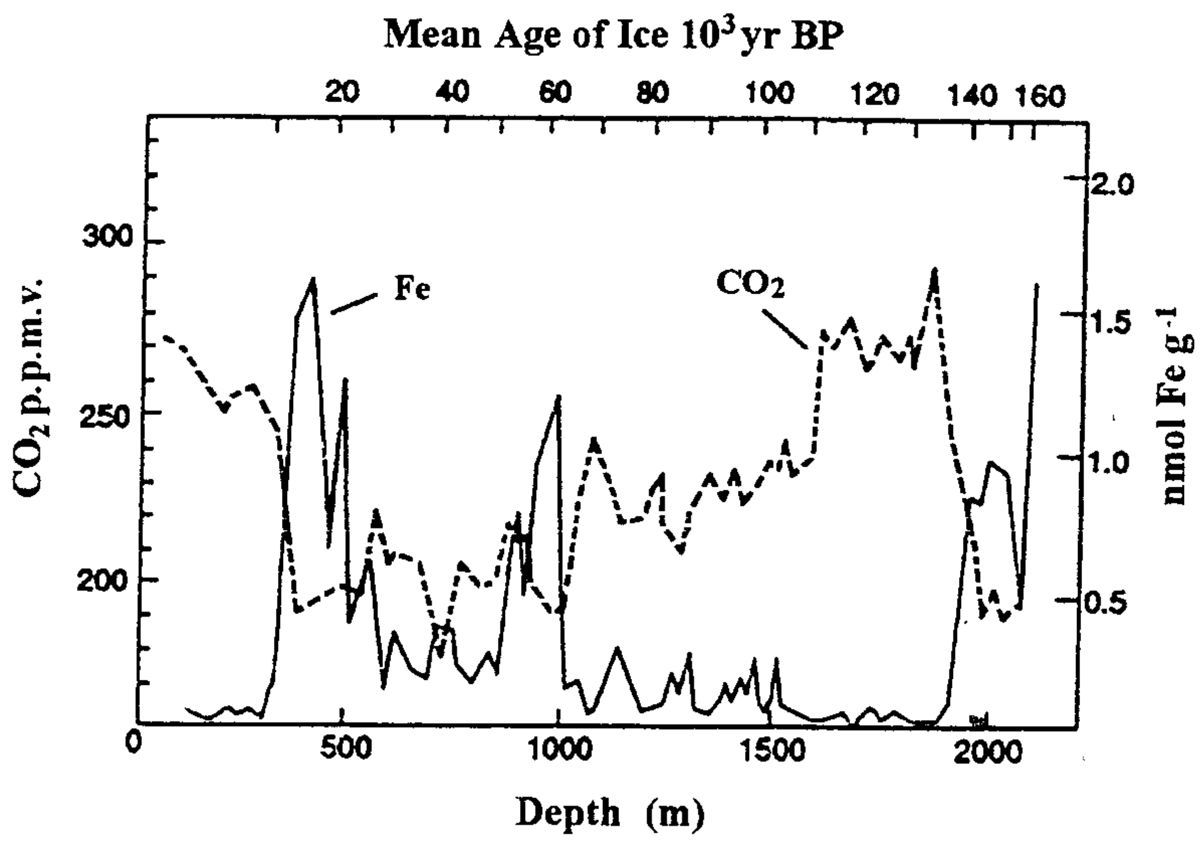

FIGURE 9.17. The historical record of atmospheric CO_2, dust deposition, and nonseasalt aerosols.

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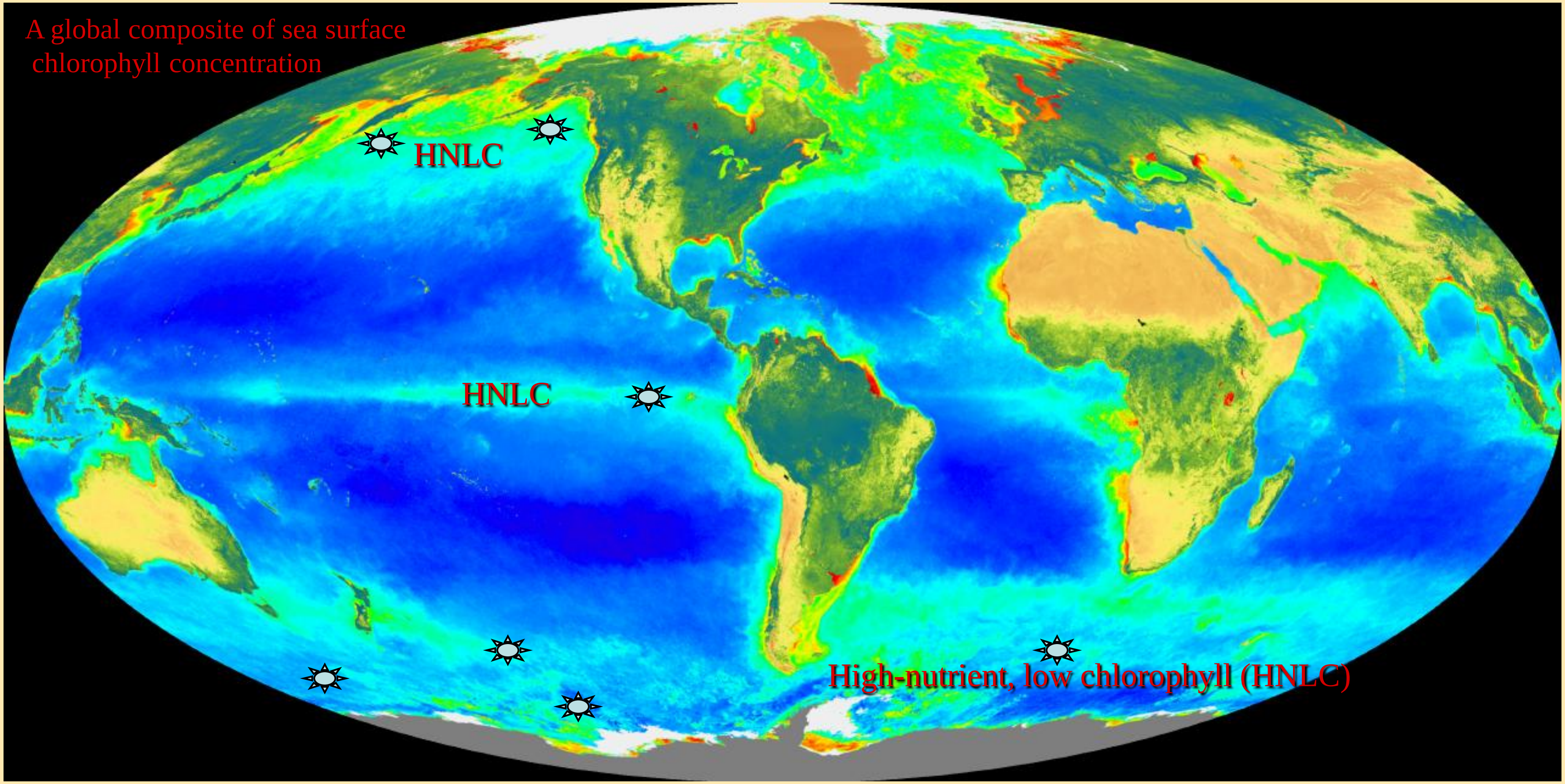
Large-Scale Fe Fertilization Experiments



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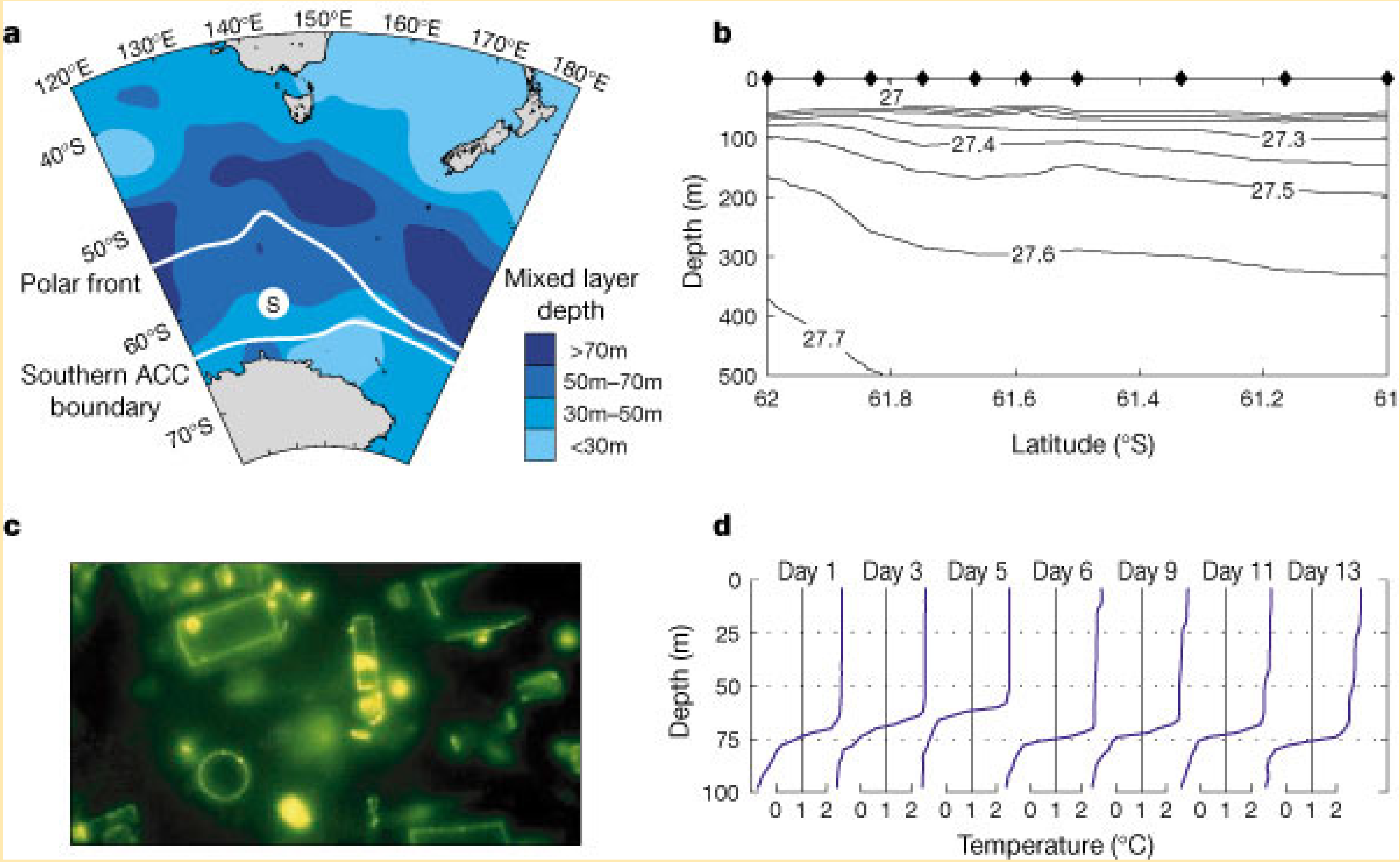
Boyd, P. W., et al. (2000) A mesoscale phytoplankton bloom in the polar Southern Ocean stimulated by iron fertilization. *Nature* 407: 695 - 702.



Primary production

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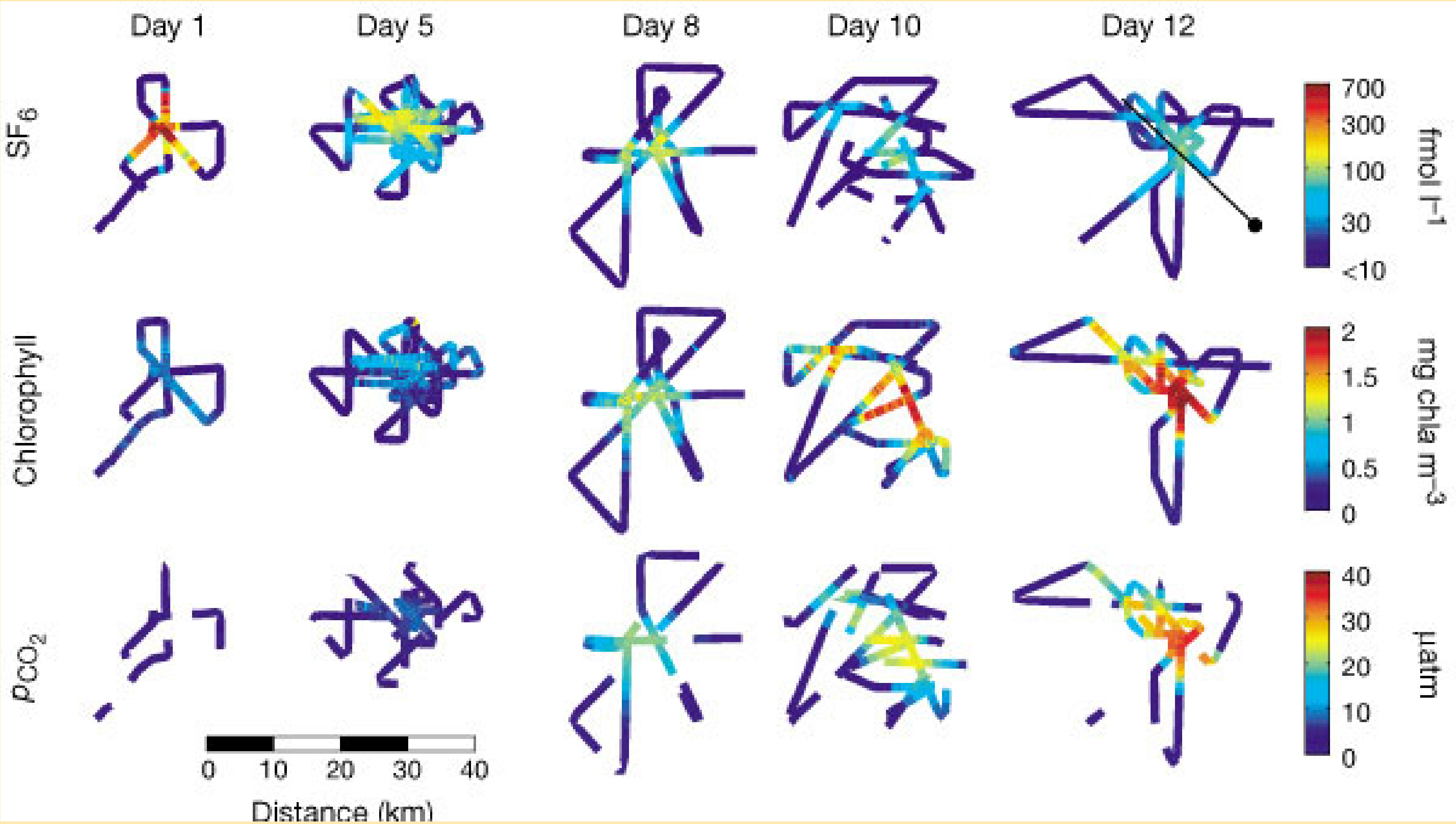

Primary production

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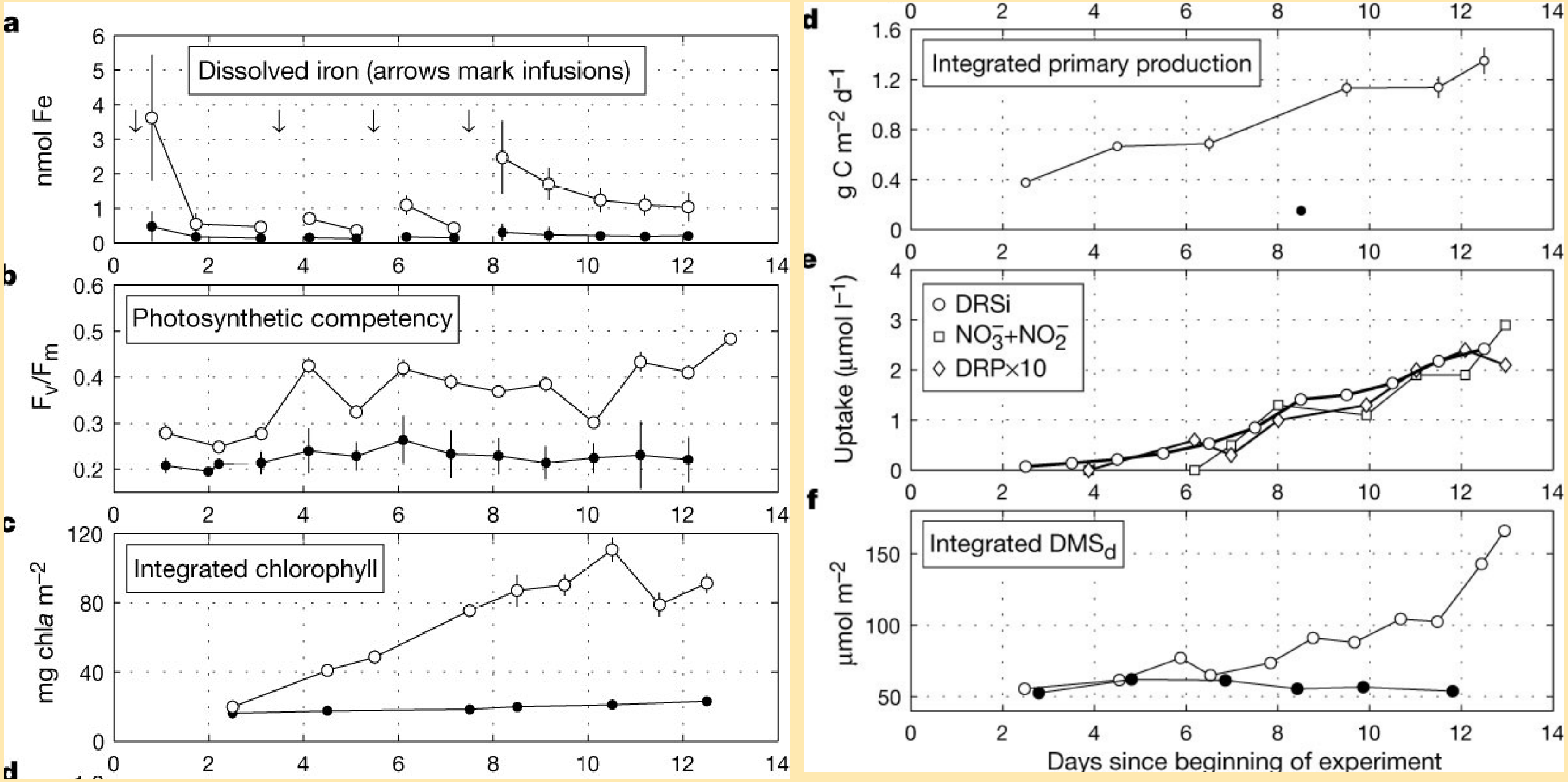
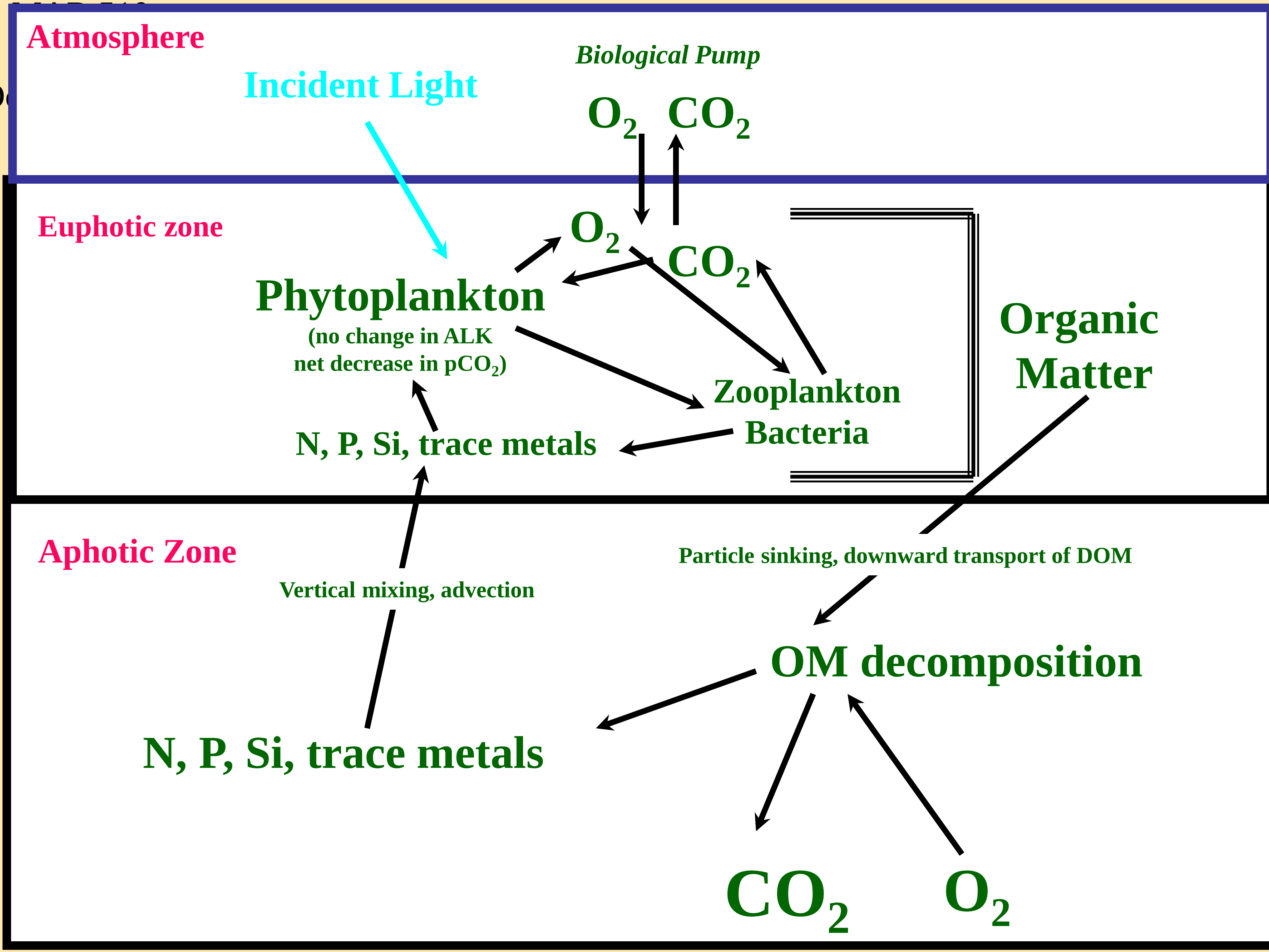


Primary production



Atmosphere
Biological Pump
Incident Light
O_2
CO_2
Euphotic zone
O_2
CO_2
Phytoplankton
(no change in ALK
net decrease in pCO_2)
Organic
Matter
Zooplankton
Bacteria
N, P, Si, trace metals
Aphotic Zone
Particle sinking, downward transport of DOM
Vertical mixing, advection
OM decomposition
N, P, Si, trace metals
CO_2
O_2

MAR 51[illegible]
Chemi[illegible]
Oceanog[illegible]

Alldredge and Silver (1988) Prog. Oceanogr.

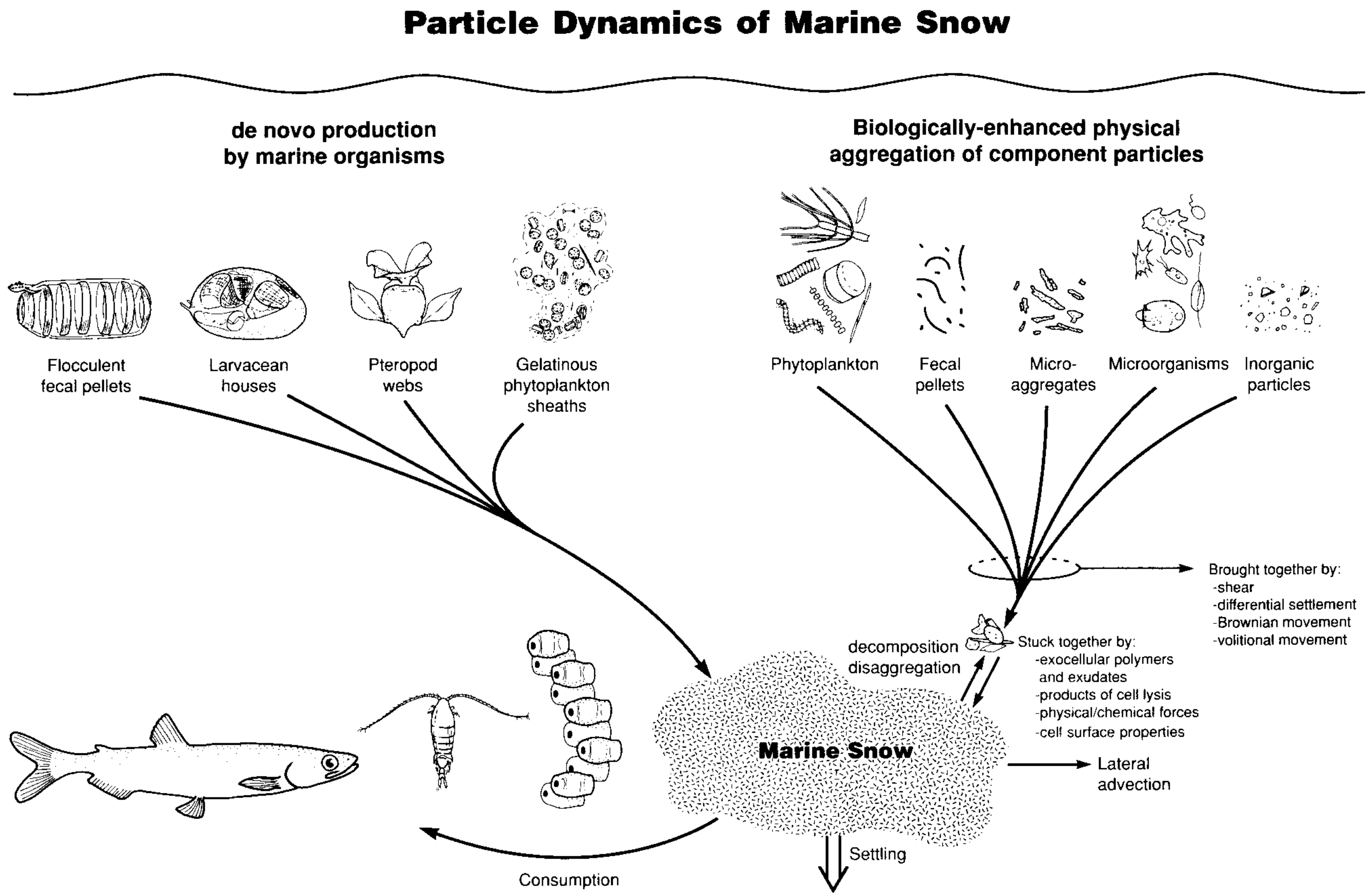


FIG.5. Major processes by which marine snow is produced, broken down and lost from the pelagic zone. Marine snow is produced by two major pathways. First, marine plankton produce marine snow aggregates *de novo* as mucus webs, houses, sheaths, and flocculent fecal pellets. Second, smaller component particles, including phytoplankton, fecal pellets, microaggregates, bacteria and inorganic particles, collide together via physical processes and become stuck together, facilitated by biological "glues". Snow is broken down or lost by processes of decomposition, disaggregation, consumption, lateral advection and settlement.

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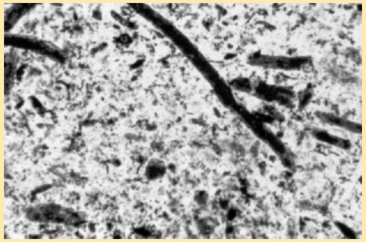
ken from sediment traps; the shorter fecal pellets are several millimeters long. (D) An enlargement of the fecal pellet in (C), showing that it contains small particles of detritus. Photo courtesy of Michael Peterson, University of Washington.



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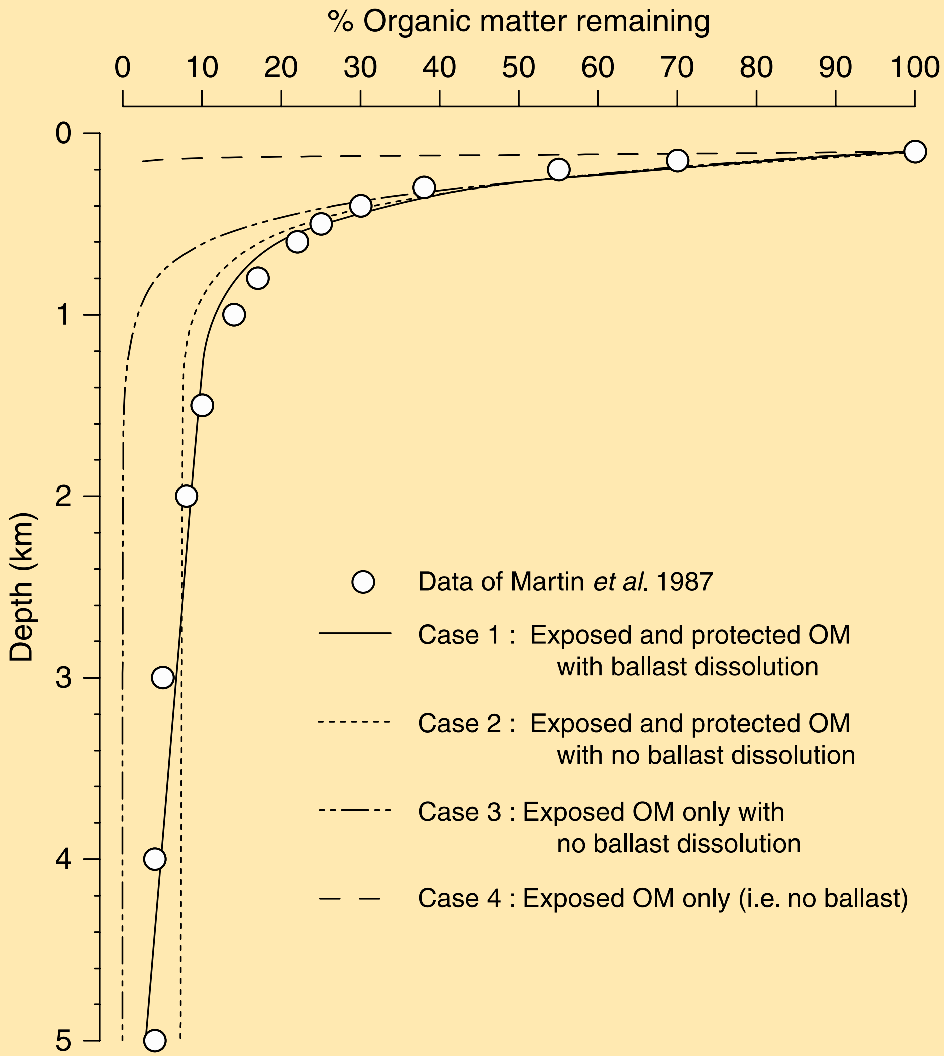

Figure 6.10. Comparison of the organic matter remaining as a function of depth in sediment traps (circles, from Martin *et al.*, 1987) with predictions using a Stokes settling model for several different cases. Particles were 60 % organic matter mass and 40 % mineral mass with an initial diameter of 125 μm. Densities were: $\rho_{seawater} = 1.0$, $\rho_{OM} = 1.1$, $\rho_{min} = 2.5\ g\ cm^{-3}$. Organic matter degradation rates were 0.87 d^{-1} and mineral dissolution rates were 0.044 d^{-1}. Sinking particulate organic matter can fit the measured values only if it contains mineral ballast and some of it is protected from degradation. From Michael Peterson, unpublished results.

Primary production

From W. Deuser

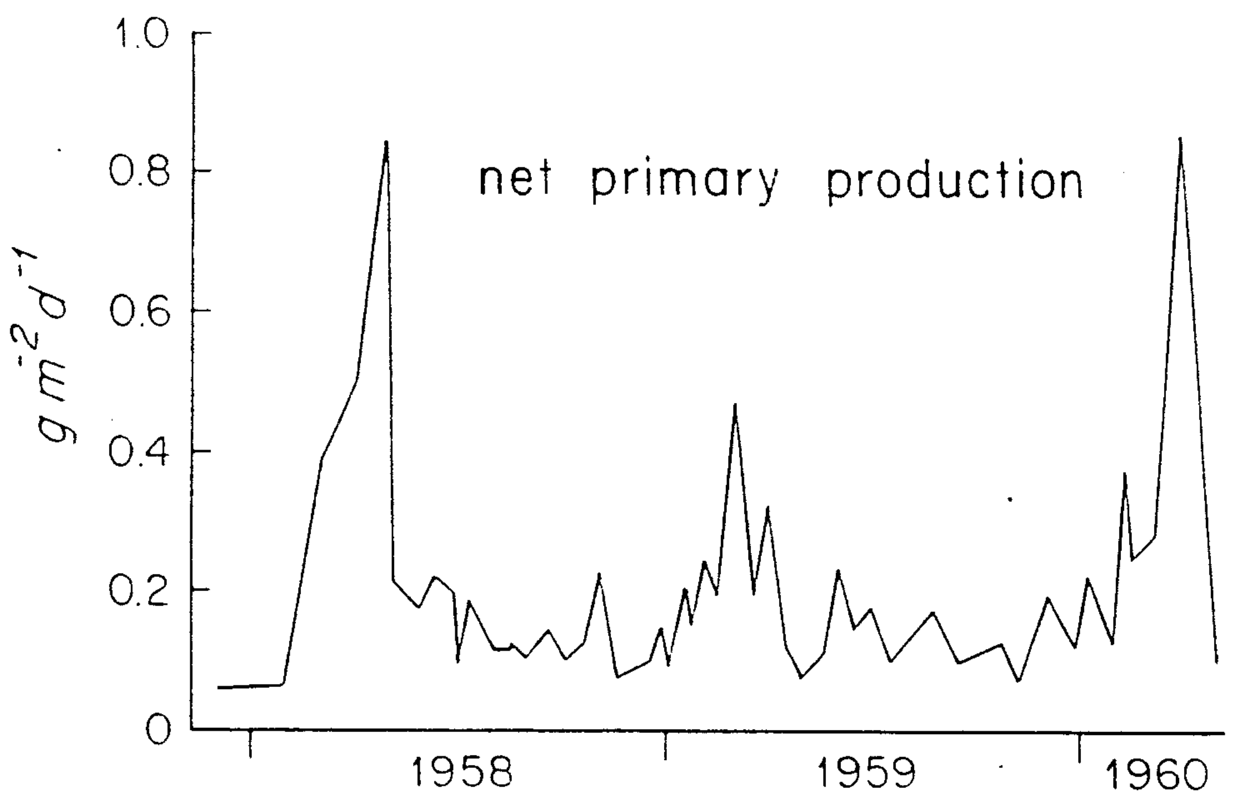

Fig. 3: Variations in net carbon assimilation at Station 'S' (Menzel and Ryther, 1961)

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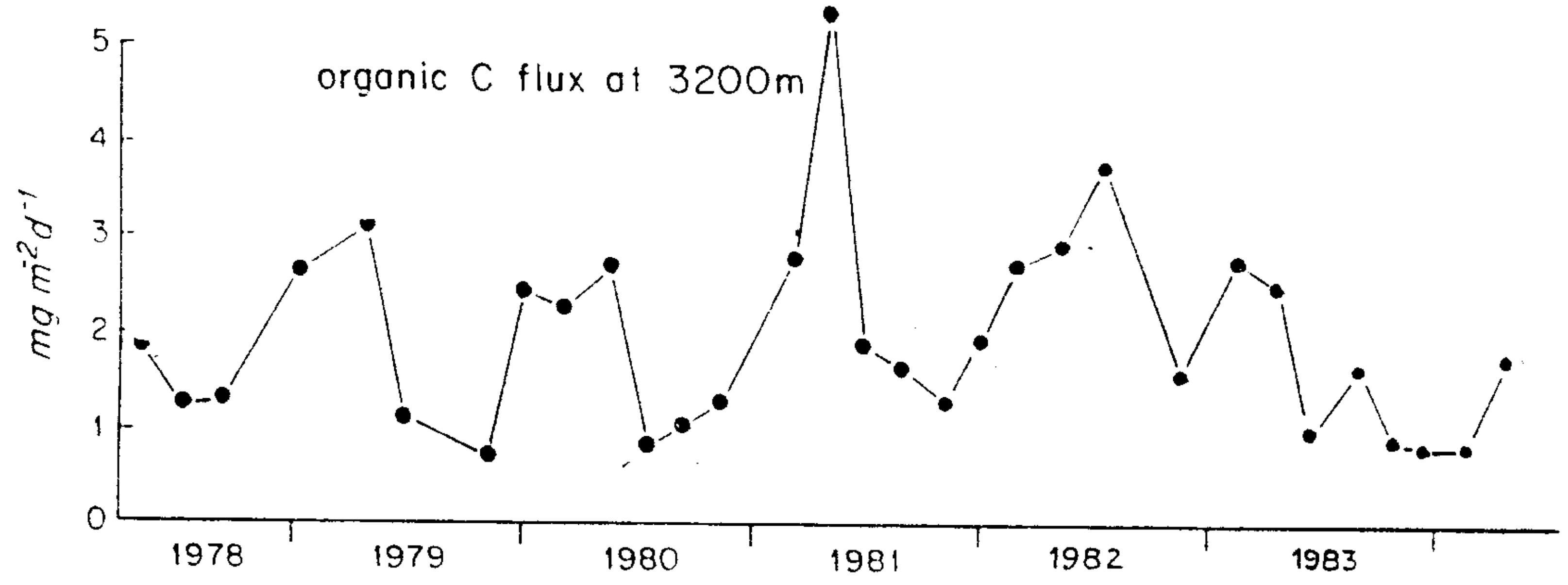

Six-year record of variations in deep-water organic-carbon flux southeast of Bermuda

Primary production

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Table 6.1. *The annual organic carbon export from the surface ocean determined at three time series locations by different methods*

These locations are the time series stations at BATS (near Bermuda), HOT (near Hawaii), and Station P (in the subarctic Pacific). Total organic C flux at BATS is the sum of the sediment trap and DOC flux. At HOT it is the sum of the ^{234}Th particle flux, DOC flux, DOC accumulation rate (0.3 mol C m^{-2} y^{-1}) and zooplankton migration flux (0.2 mol C m^{-2} y^{-1}).

	Organic C (mol m^{-2} y^{-1})		
	Subtropical Atlantic (BATS)	Subtropical Pacific (HOT)	Subarctic Pacific (Station P)
^{14}C primary productivity	12.7[a]	14.6[b]	17.9[c]
Estimates of organic C export			
Sediment traps	0.7[d]	0.8 ± 0.1[e,f]	
^{234}Th particle flux		1.5 ± 1.0[f]	
DOC flux	1.1 ± 0.1[d]	0.4 ± 0.2[e,f]	
Total organic C flux	1.8 ± 0.1[d]	2.4 ± 0.9[f]	
Oxygen mass balance	3.6 ± 0.6[g]	2.7 ± 1.7[e], 1.1–1.7[l]	2.0 ± 1.0[h]
DIC and $\delta^{13}C$ DIC	3.5 ± 0.5[i]	2.7 ± 1.3[j]	
^3H–^3He (OUR)	2.8[k]		

[a] Michaels and Knap (1996)
[b] Karl *et al.* (1996)
[c] Varela and Harrison (1999)
[d] Carlson *et al.* (1994)
[e] Emerson *et al.* (1997)
[f] Benitez-Nelson *et al.* (2001)
[g] Spitzer and Jenkins (1989)
[h] Emerson *et al.* (1991)
[i] Gruber *et al.* (1998)
[j] Quay and Stutzman (2003)
[k] Jenkins and Wallace (1992)
[l] Hamme and Emerson (2006)