Primary Productivity in Ocean

Primary Production The conversion of the inorganic carbon, usually in the form of carbon dioxide, into organic compounds by autotrophs.

Primary Productivity The rate of primary production, that is, the amount of carbon fixed under a square meter of sea surface in a day or in a year.

So marine primary producers include:

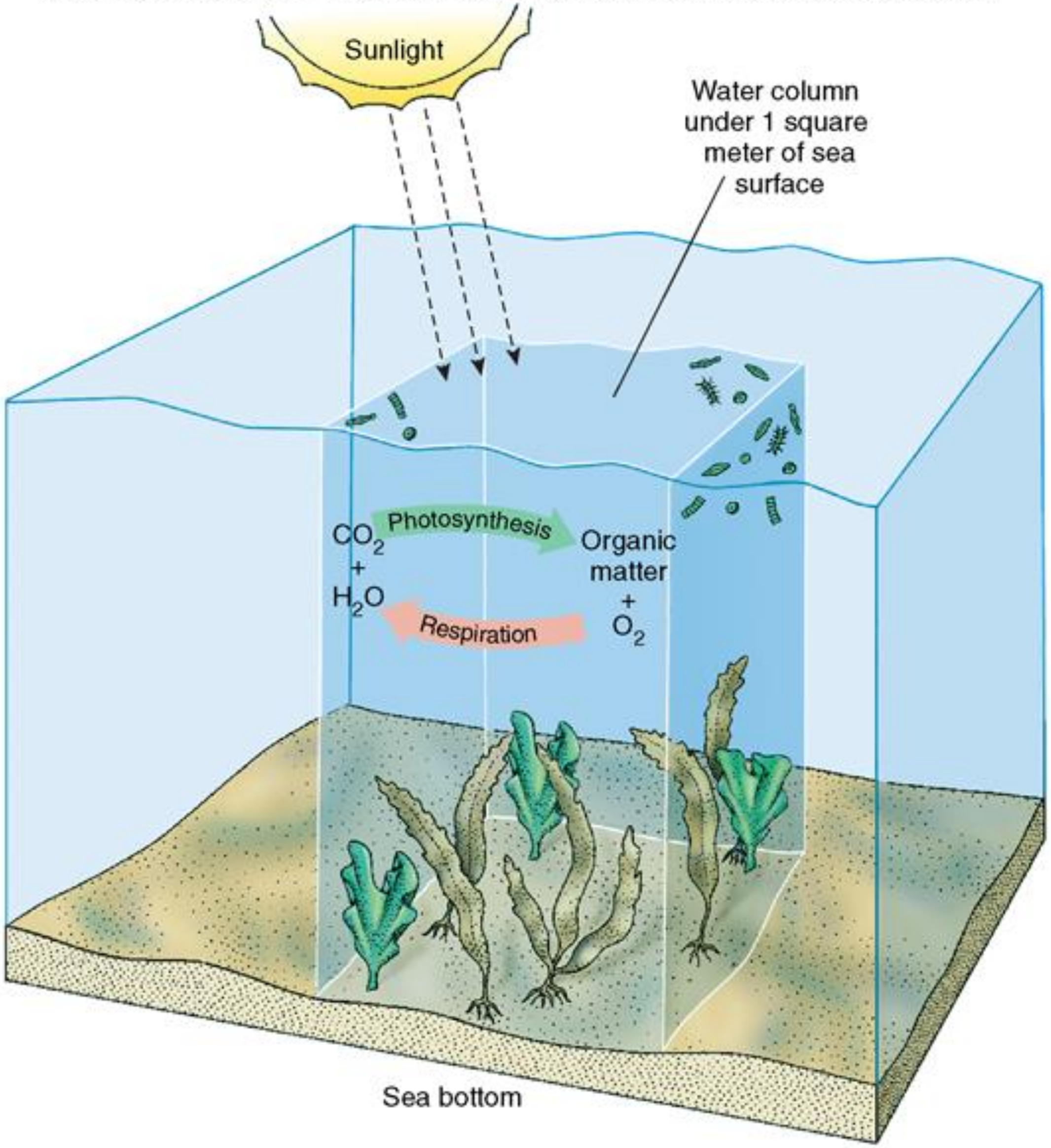
Cyanobacteria

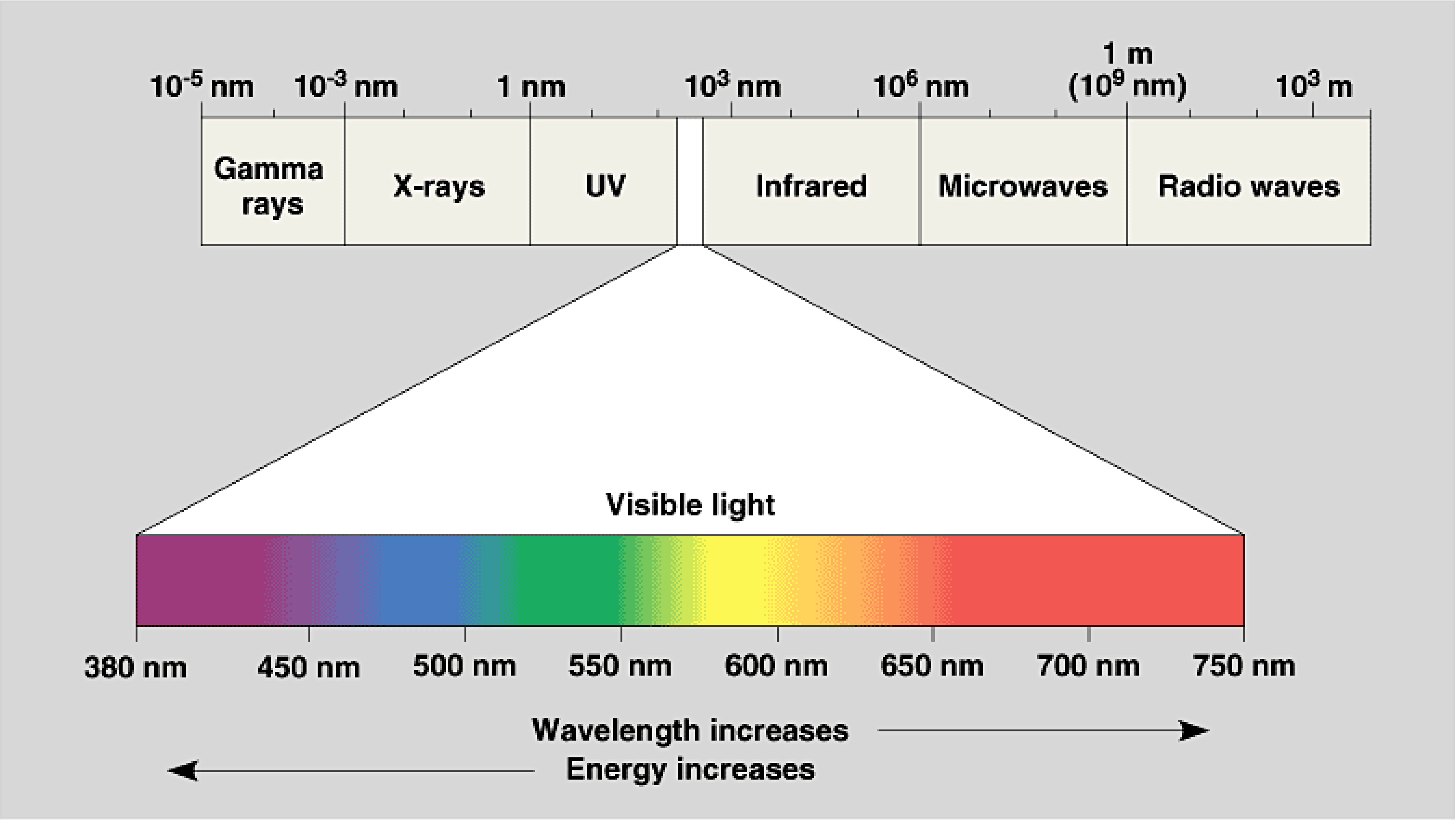
Microalgae

Macroalgae

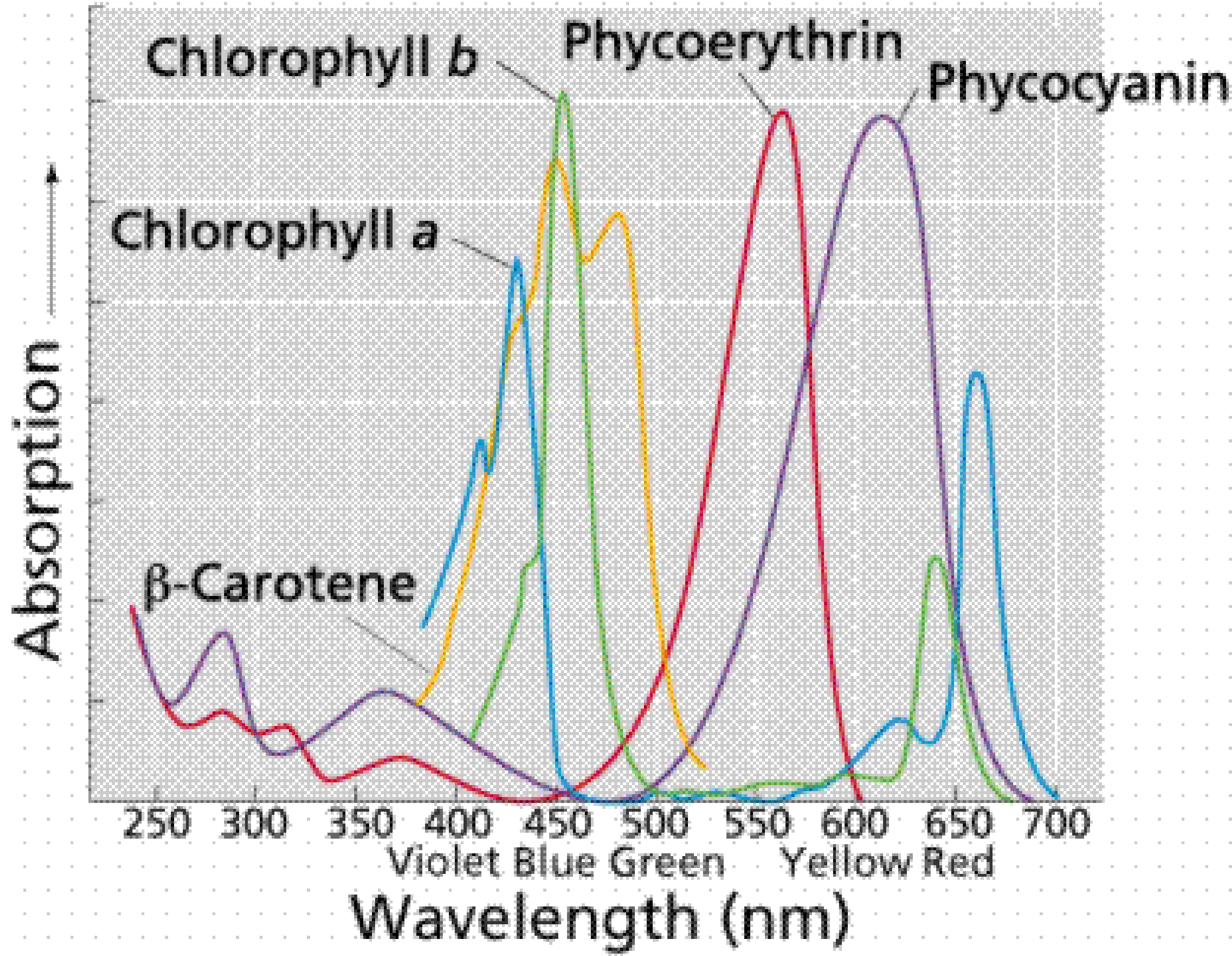
Seagrasses

….



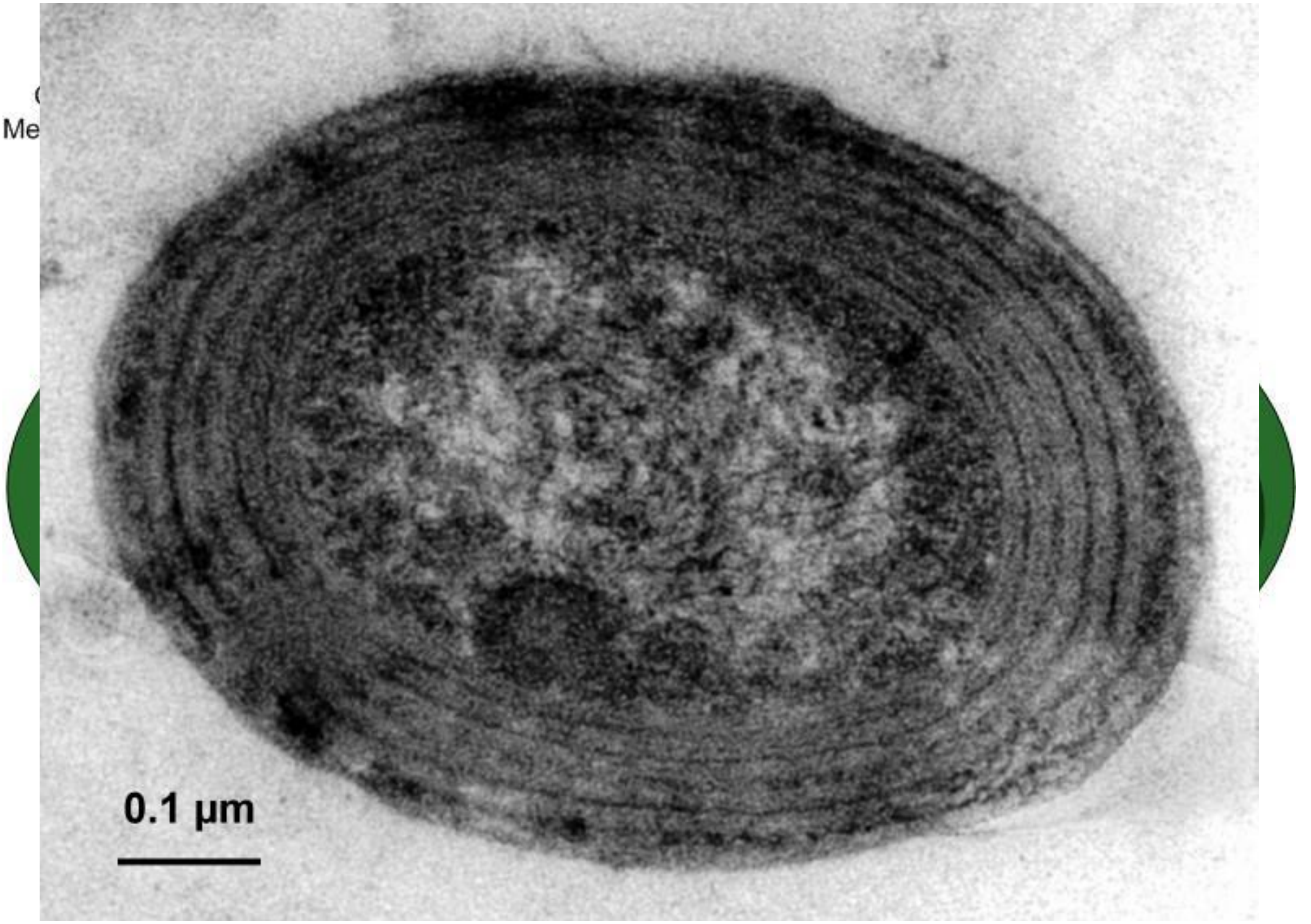


photosynthetically available radiation (PAR)



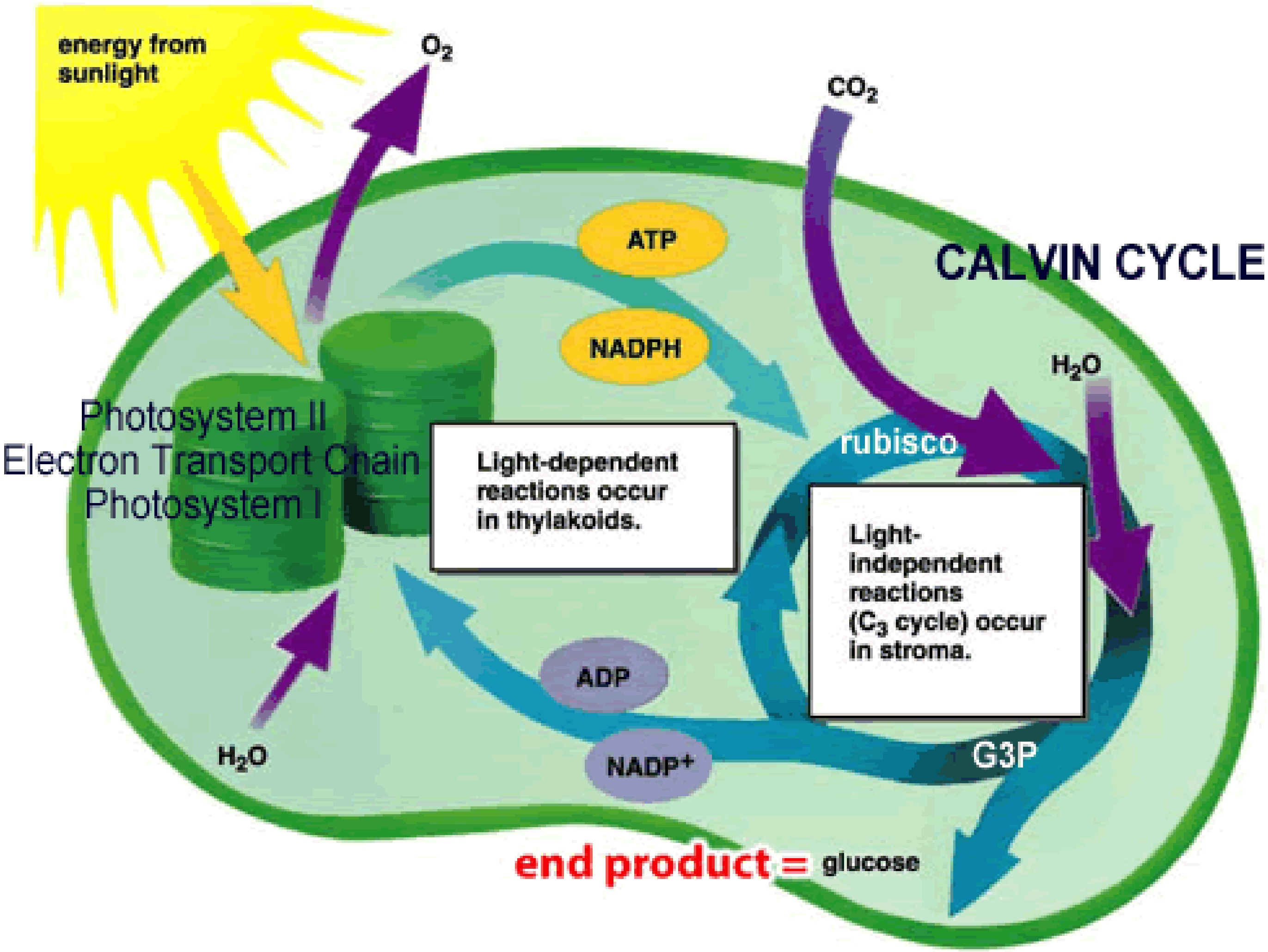
Chlorophyll b
Phycoerythrin
Phycocyanin
Chlorophyll a
β-Carotene
Absorption
250 300 350 400 450 500 550 600 650 700
Violet Blue Green Yellow Red
Wavelength (nm)

Chloroplast



Photosynthesis consists of light and dark reactions:

- The **light reactions** are associated with the thylakoid membranes and consist of the activities of photosystems I and II. These activities use the energy of photons to produce a proton gradient and reducing power.
- The **dark reactions** use the energy of the light reactions to fix carbon dioxide and synthesize carbohydrates. These reactions are referred to as the **Calvin cycle**, and take place in the stroma.



energy from sunlight
O_2
CO_2
ATP
NADPH
CALVIN CYCLE
H_2O
Photosystem II
Electron Transport Chain
Photosystem I
Light-dependent reactions occur in thylakoids.
rubisco
Light-independent reactions (C_3 cycle) occur in stroma.
ADP
$NADP^+$
G3P
H_2O
end product = glucose

Photosynthesis

Light reaction:

H_2O -> Photo systems I & II ---> O_2 + $NADP^+$ + ATP

Dark reaction:

CO_2 + $NADP^+$ + ATP ----> Calvin cycle -> $(CH_2O)_6$

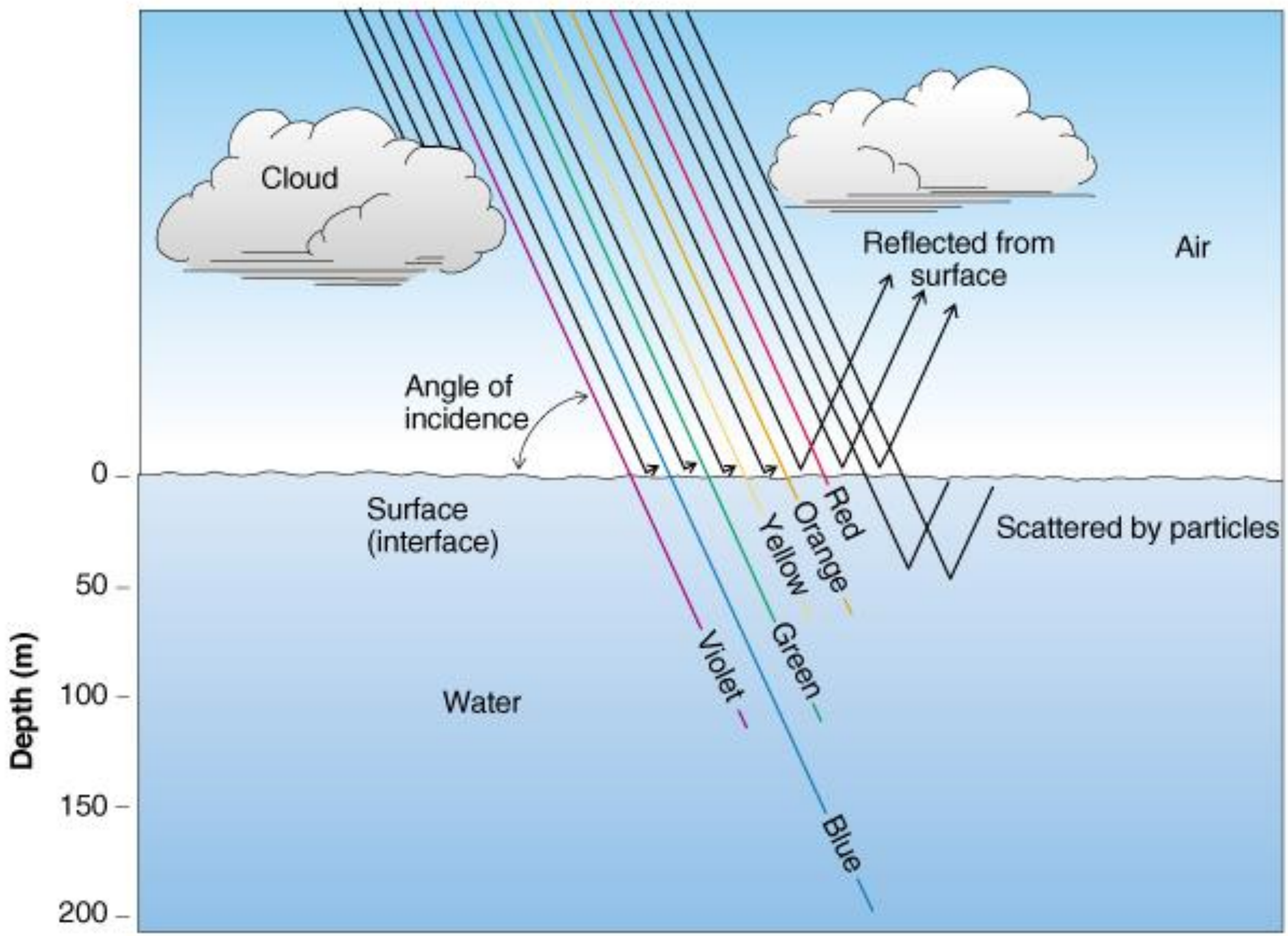
The overall equation for photosynthesis is:

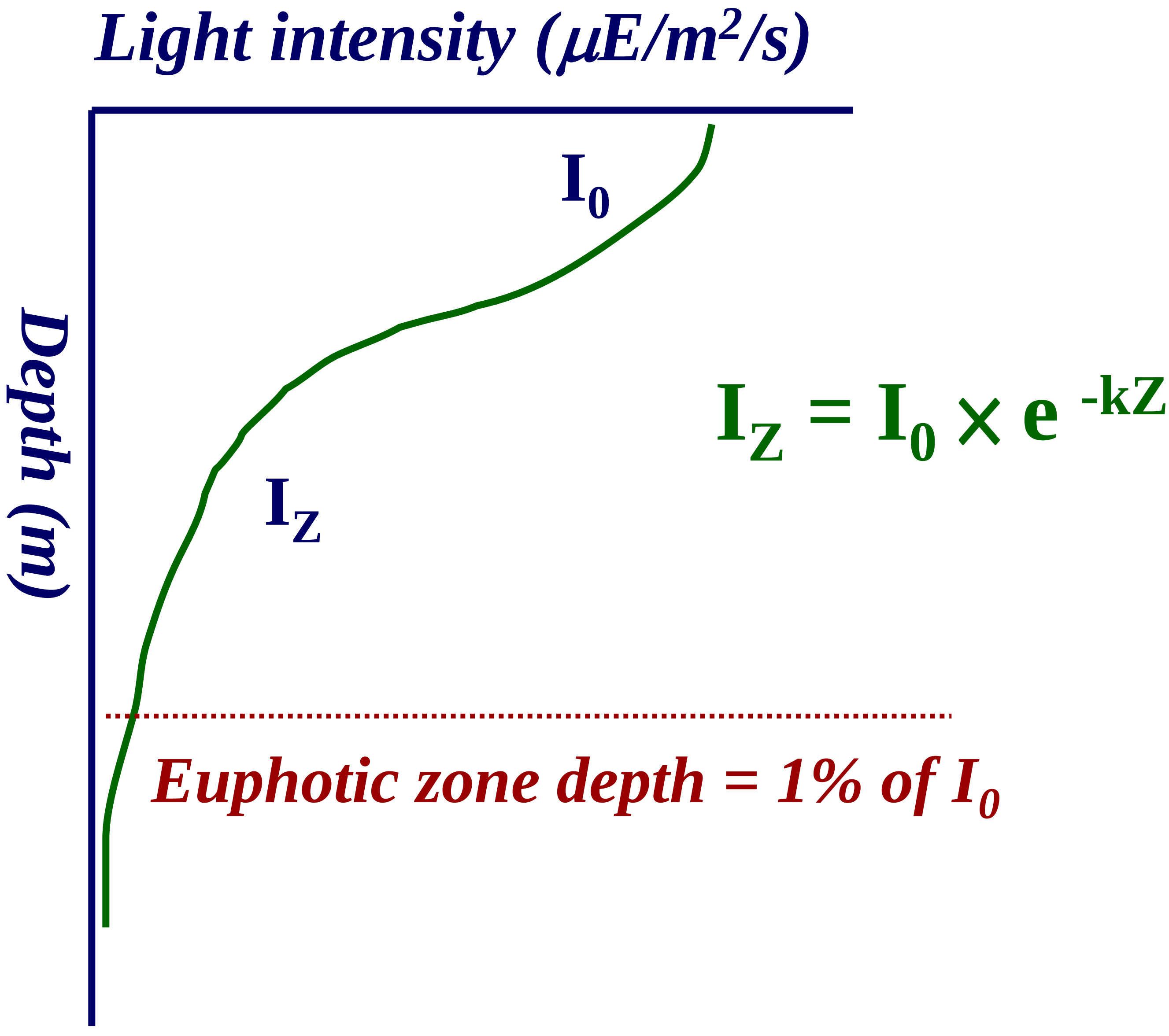
$$6\,CO_2 + 6\,H_2O \xrightarrow{\text{light}} C_6H_{12}O_6 + 6\,O_2$$

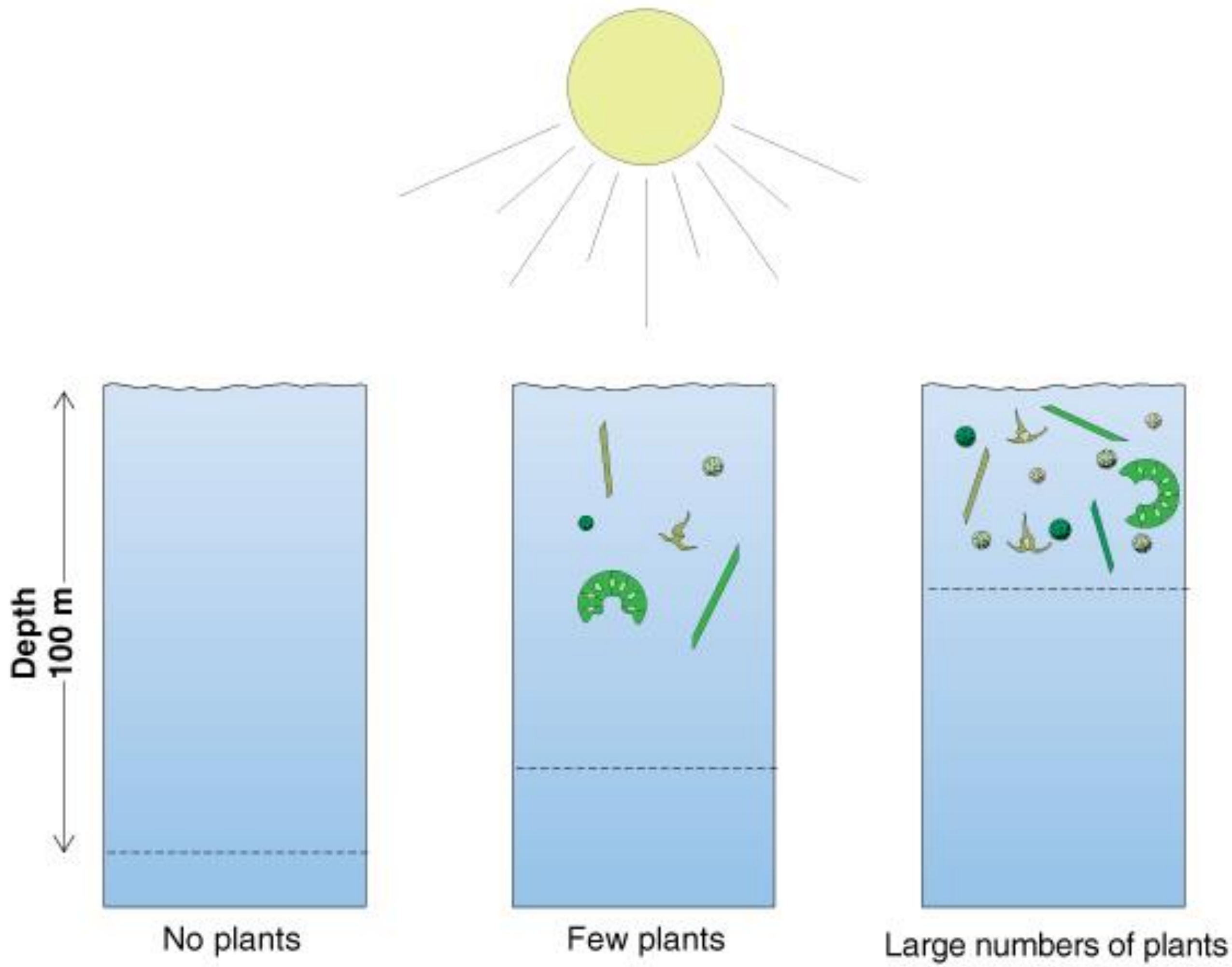
Limiting factors for photosynthesis

$$PP = f\,(L, N, T, G)$$

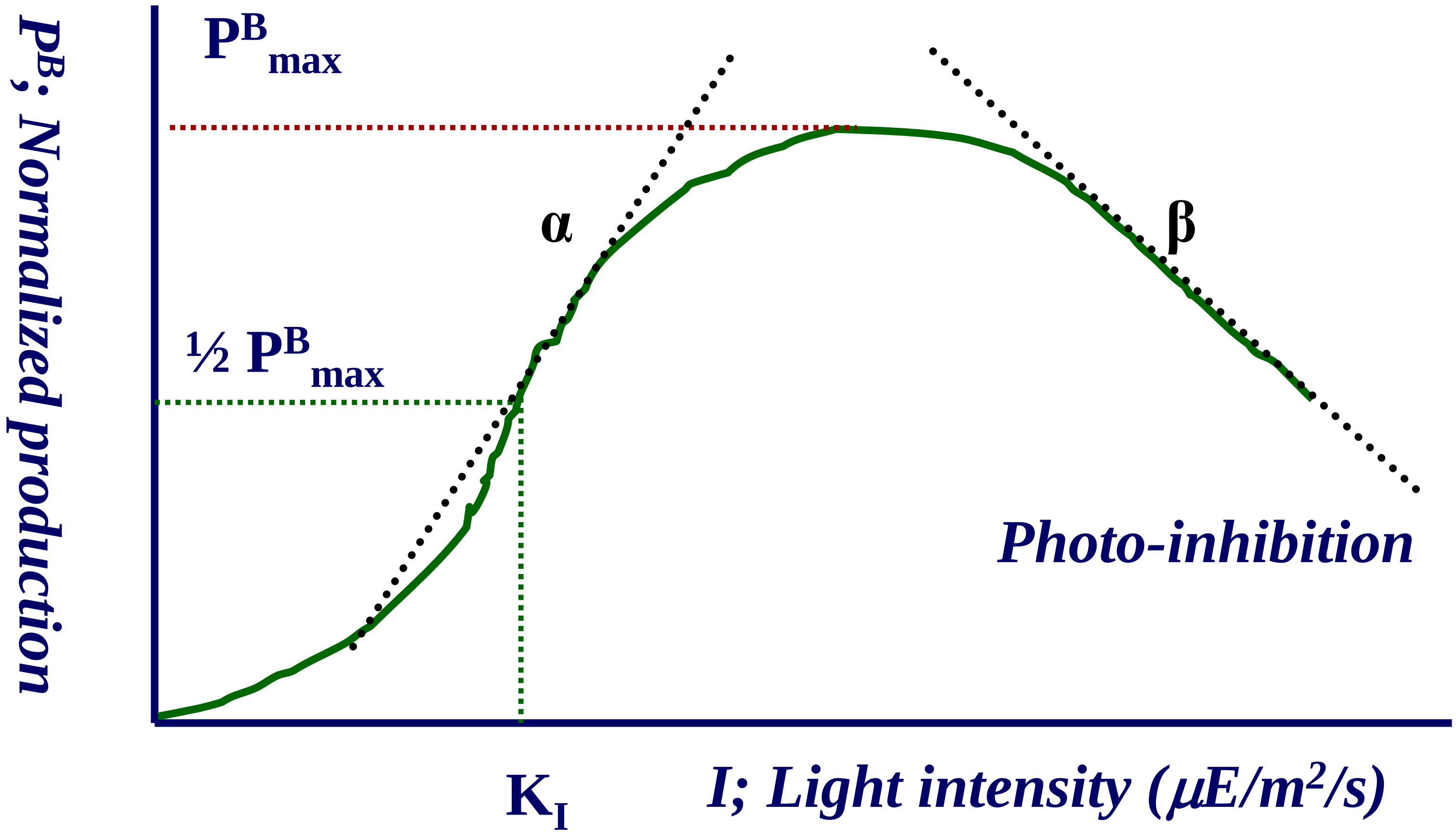
Light intensity
Nutrients: N, P, S_i & Fe
Temperature
Grazing (zooplankton)


Cloud
Reflected from surface
Air
Angle of incidence
0
Surface (interface)
Red
Orange
Yellow
Scattered by particles
50
Violet
Green
Depth (m)
100
Water
150
Blue
200


Light intensity (μE/m2/s)
Depth (m)
I0
IZ
IZ = I0 × e -kZ
Euphotic zone depth = 1% of I0

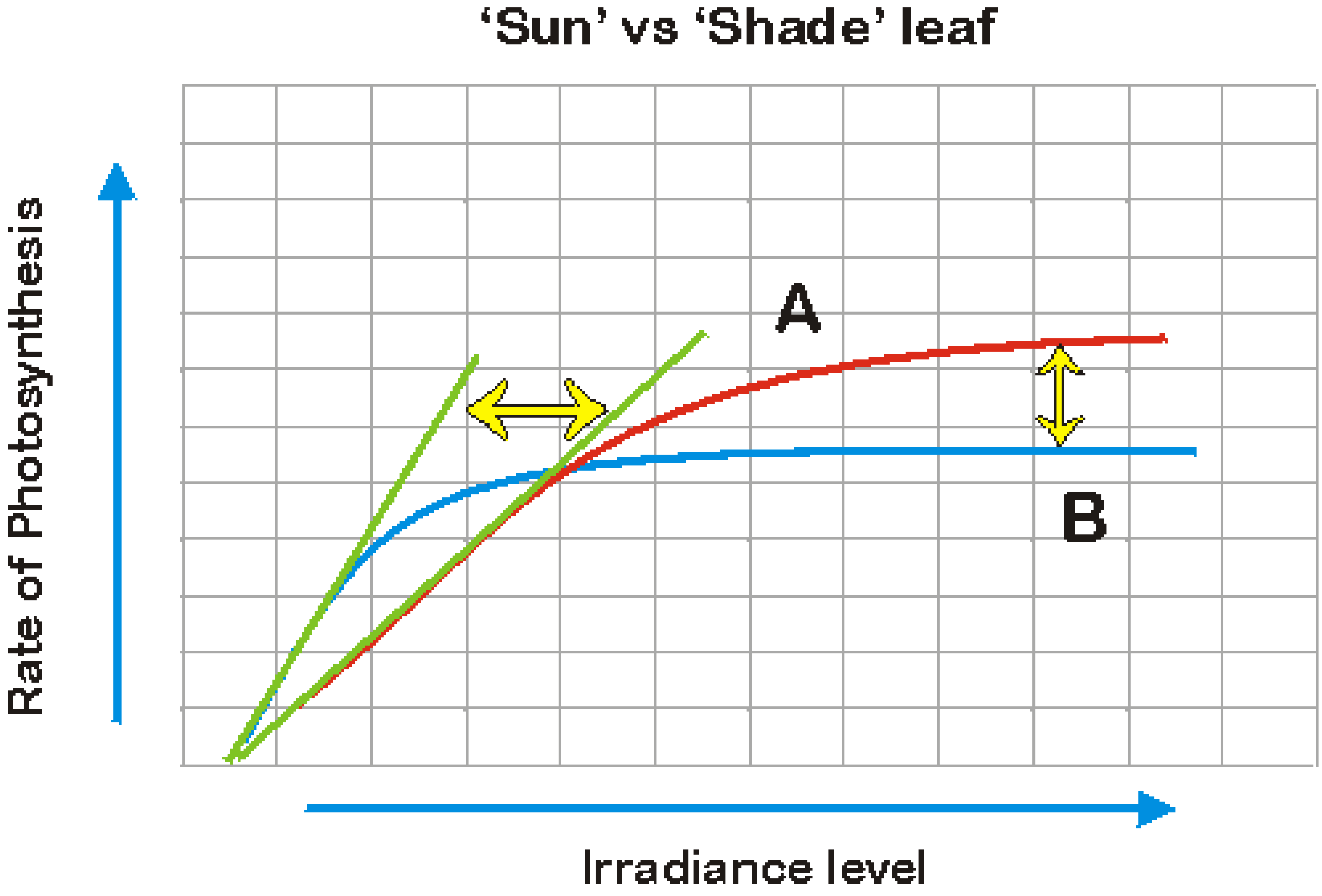


Euphotic zone depth varies with suspended particles and dissolved organic matter in the water column

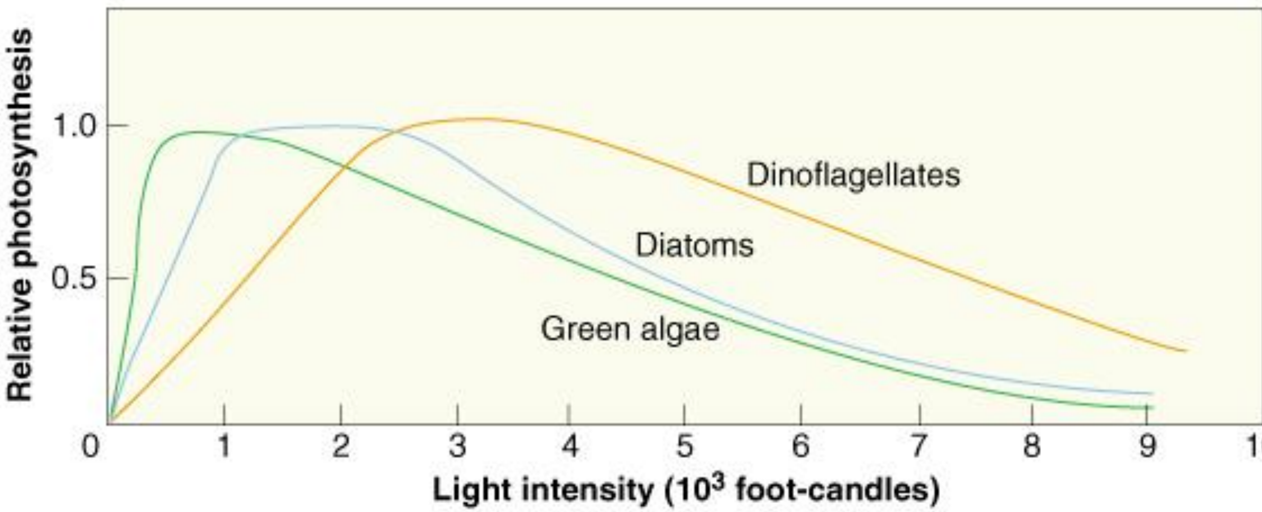


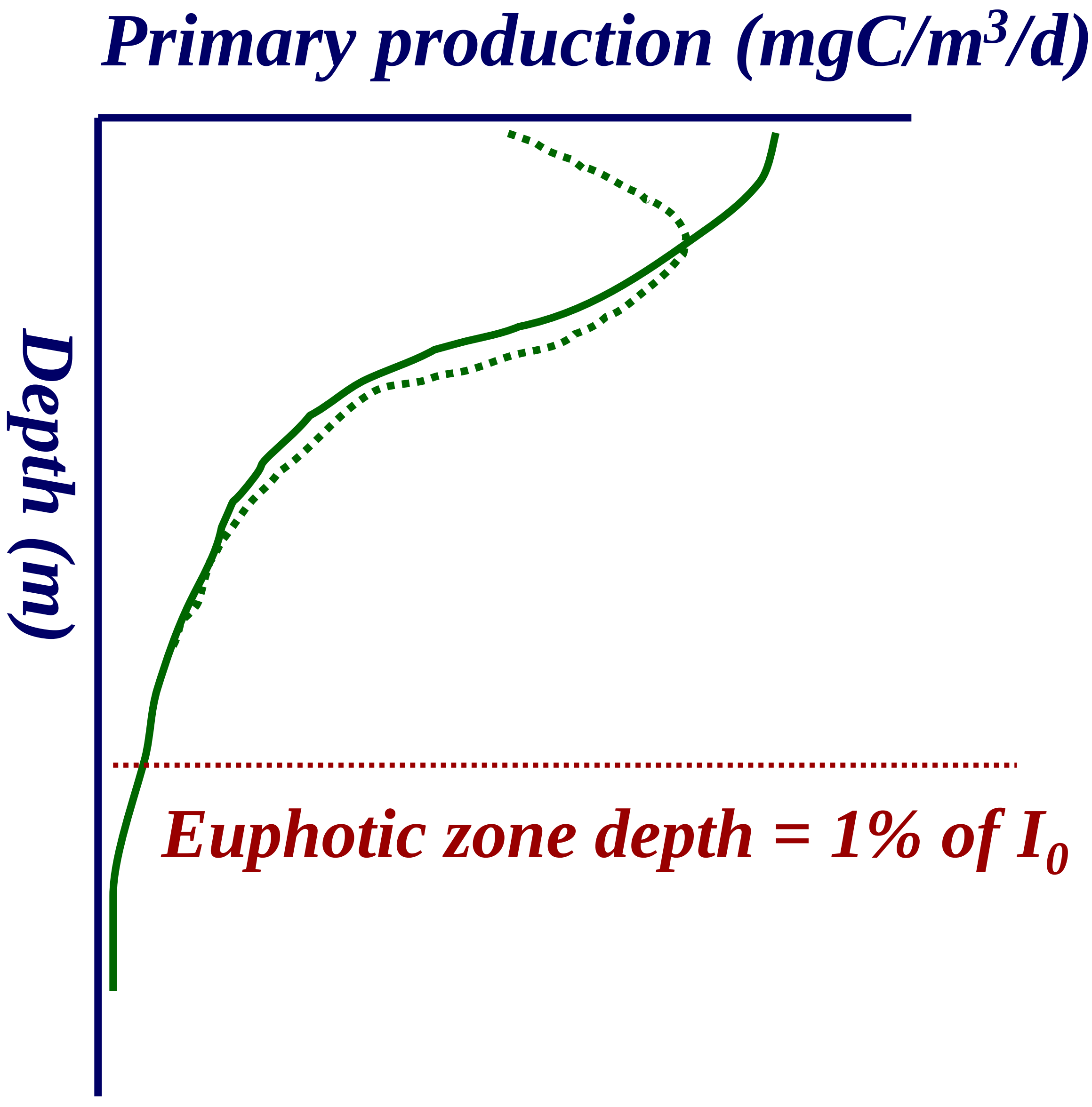
$$P^B = P^B_{max} \times [\ I \ / \ (K_I + I)\ ]$$

Which P vs I curve would favor a sunny as opposed to shady habitat?



http://www.marietta.edu/~spilatrs/biol103/photolab/sunexpl.gif


Relative photosynthesis
1.0
0.5
Dinoflagellates
Diatoms
Green algae
0
1
2
3
4
5
6
7
8
9
10
Light intensity (10^3 foot-candles)



Primary production (mgC/m³/d)
Depth (m)
Euphotic zone depth = 1% of I₀

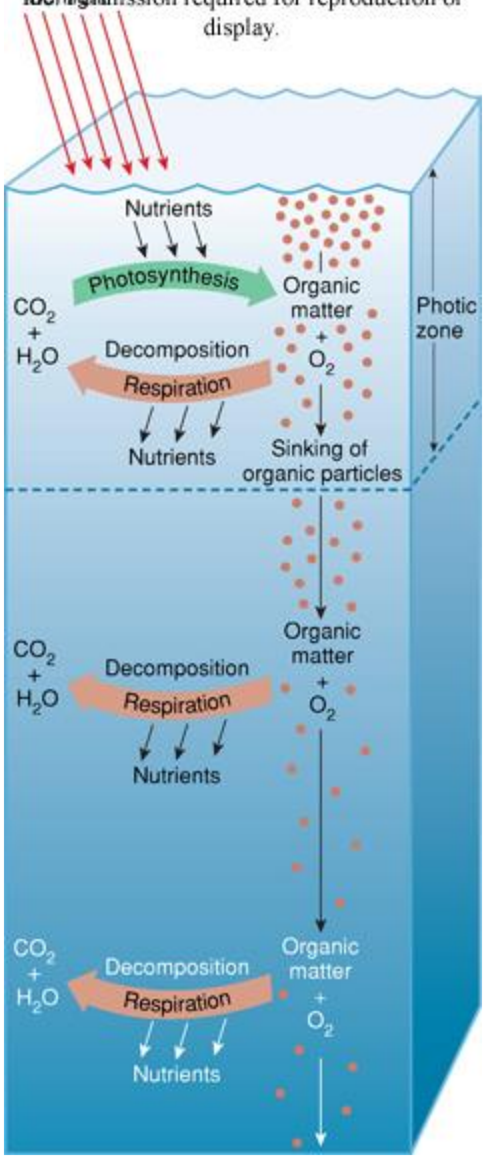
Types of nutrient

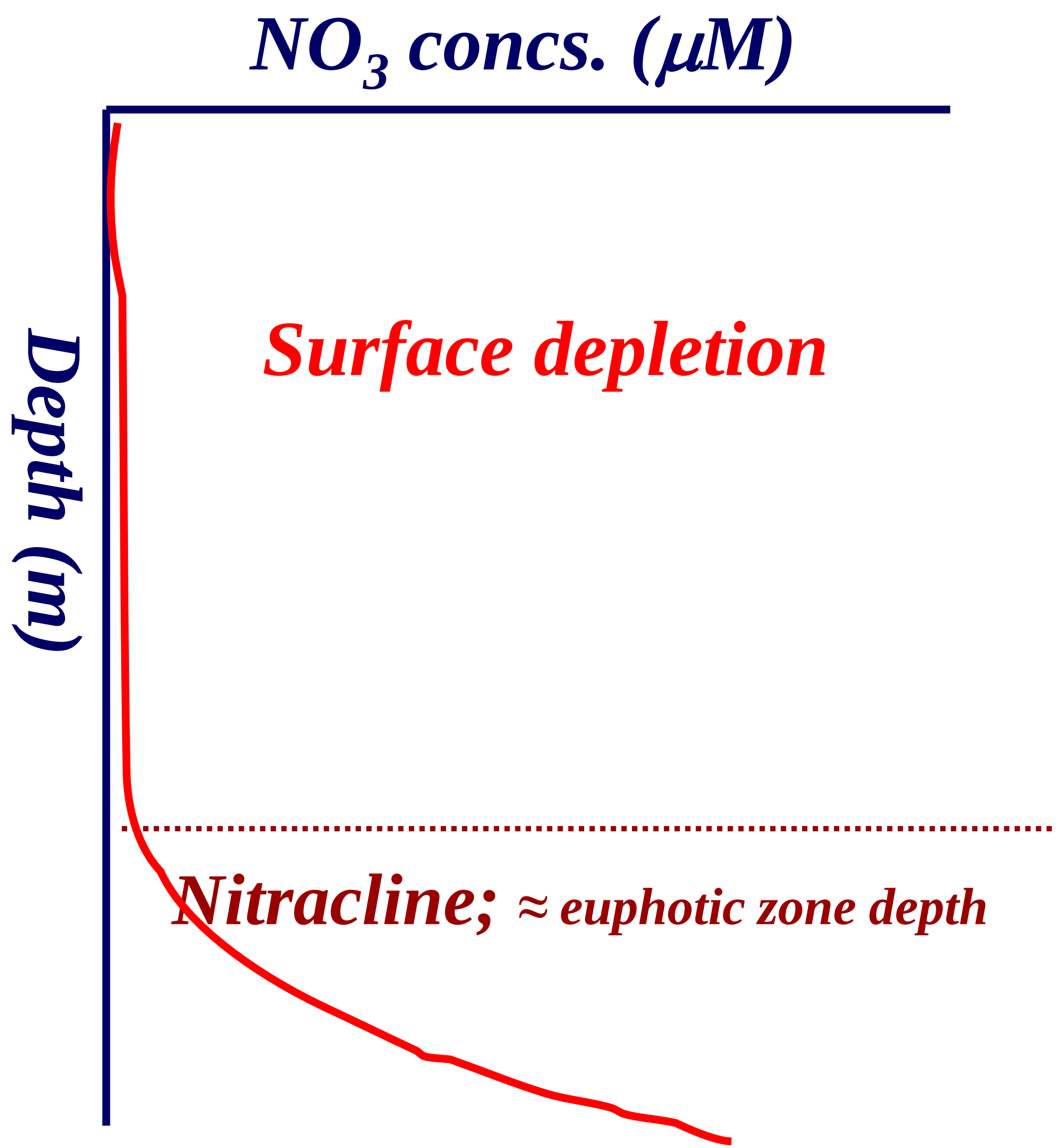
NO_3^-

PO_4^{-3}

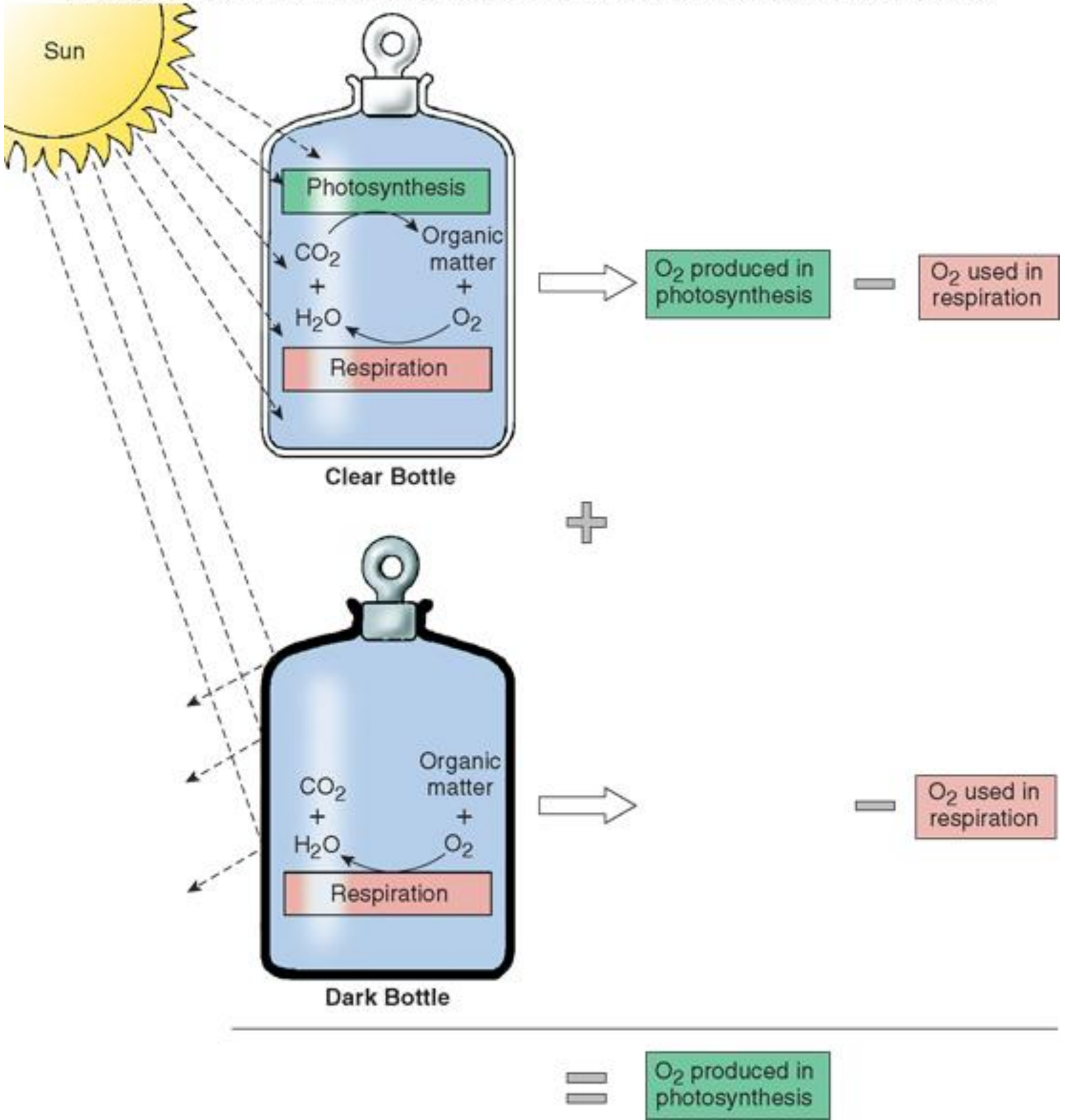
SiO_2

minor nutrients (for example, Fe^{+2})


Nutrients
Photosynthesis
Organic matter + O_2
CO_2 + H_2O
Decomposition
Respiration
Nutrients
Sinking of organic particles
Photic zone
CO_2 + H_2O
Decomposition
Respiration
Nutrients
Organic matter + O_2
CO_2 + H_2O
Decomposition
Respiration
Nutrients
Organic matter + O_2


NO_3 concs. (μM)
Depth (m)
Surface depletion
Nitracline; ≈ euphotic zone depth

Measuring primary production



O_2 method

•decreases in dissolved oxygen are used to estimate cellular respiration in the absence of light

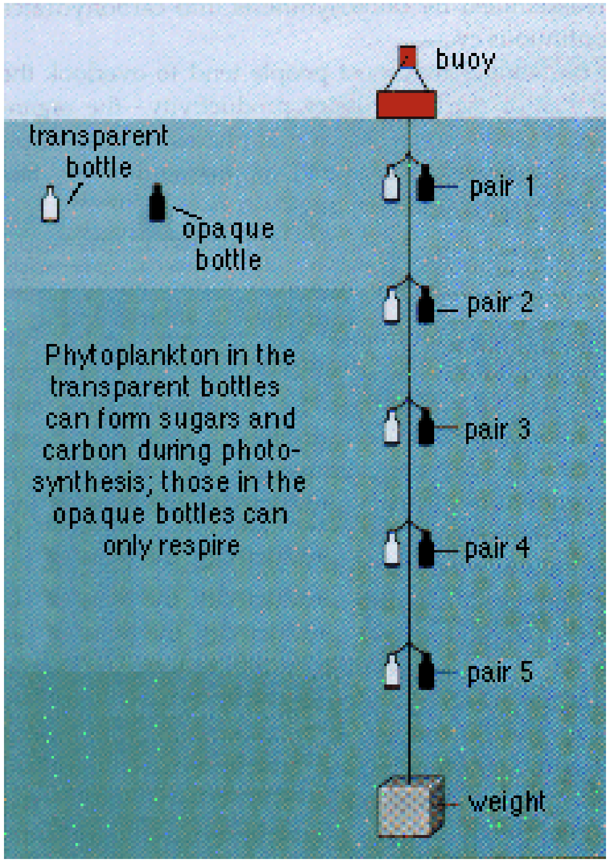
•these decreases are subtracted from the oxygen content in the light bottles to provide a measure of net photosynthesis (i.e., excess of phytoplankton production after respiration)

^{14}C method

• paired light and dark bottles are injected with a known quantity of bicarbonate containing labeled ^{14}C

•amount of assimilated radioactive carbon is measured and net primary productivity is then computed using a conversion factor; is much more accurate than the oxygen measurements, particularly when the productivity is very low

•measures something between gross and net production



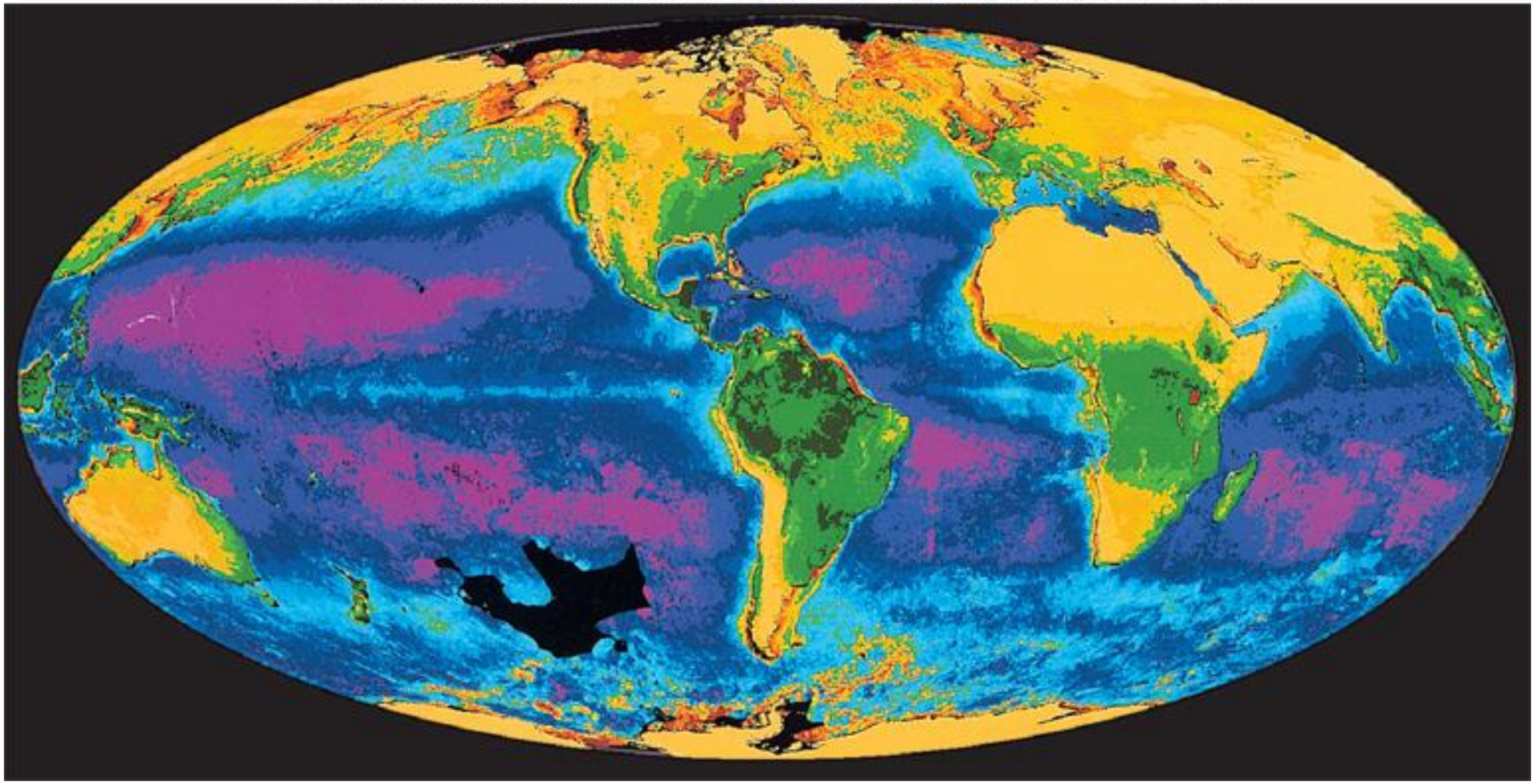
Gross production = net production + respiration

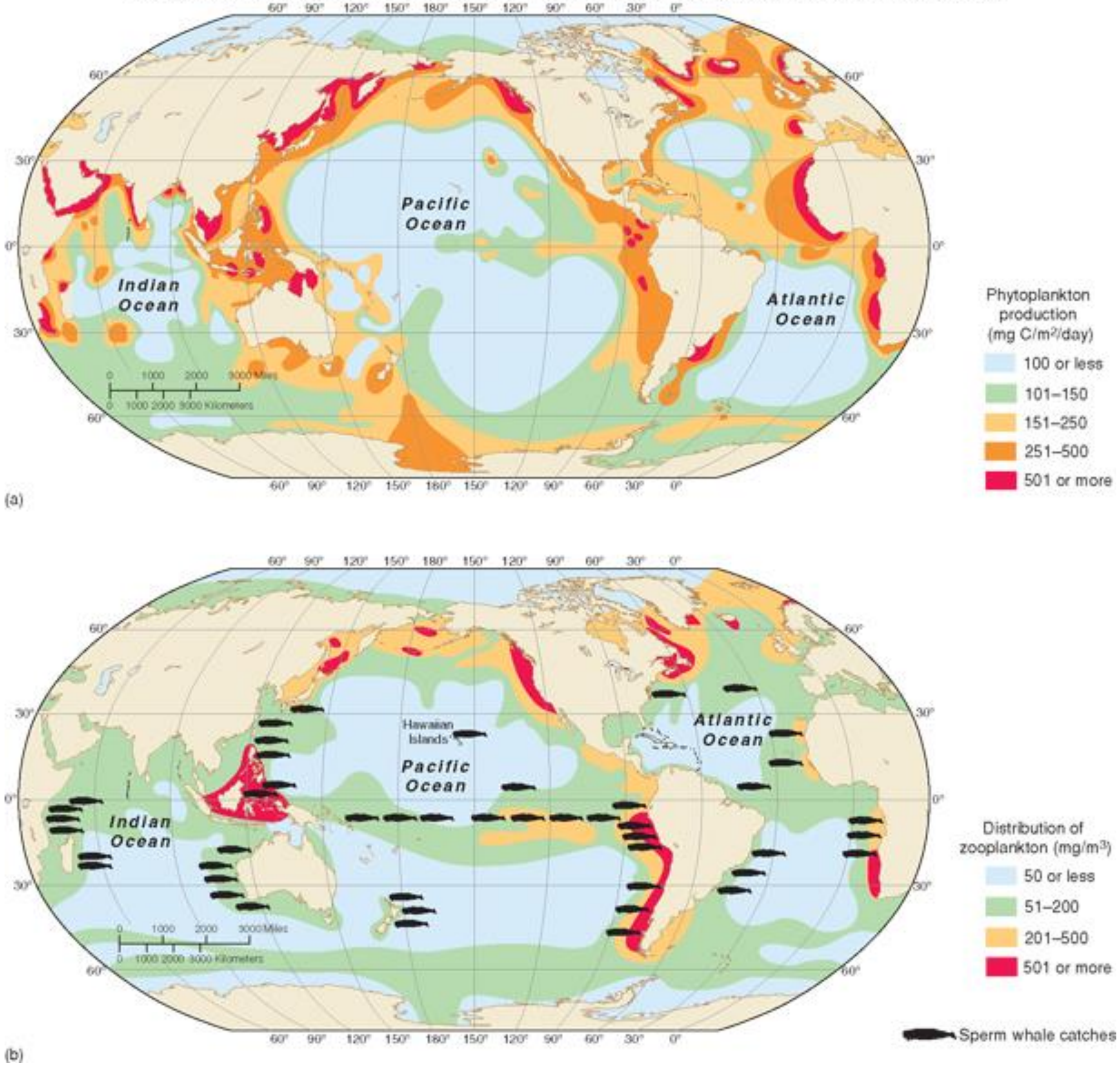
- O_2 method
  - Net production = $[O_2]_L - [O_2]_I = \Delta[O_2]_L$
  - Respiration = $[O_2]_D - [O_2]_I = \Delta[O_2]_D$
  - Gross production = $\Delta[O_2]_L + \Delta[O_2]_D$

- ^{14}C method
  - $2H_2O + {}^{14}CO_2 \rightarrow H_2O + ({}^{14}CH_2O) + O_2$
  - ${}^{14}CH_2O \rightarrow$ POC(sugars+lipids+proteins) + DOC
  - ${}^{14}C_{organic} = [{}^{14}C\ POC + {}^{14}C\ DOC]_L - [{}^{14}C\ POC + {}^{14}C\ DOC]_D$

- Rates of ^{14}C photosynthesis fall between Gross and Net Production because of 2 forms of error associated with respiratory processes:
  1) Respiration of ^{14}C-labeled photysynthate
  2) Recycling of $^{12}CO_2$ into photosynthate

Geographical variations in productivity




Pacific Ocean
Indian Ocean
Atlantic Ocean
Phytoplankton production (mg C/m²/day)
100 or less
101–150
151–250
251–500
501 or more
Hawaiian Islands
Pacific Ocean
Indian Ocean
Atlantic Ocean
Distribution of zooplankton (mg/m³)
50 or less
51–200
201–500
501 or more
Sperm whale catches

(a)

(b)

Table 10.1 Typical Rates of Primary Production in Various Marine Environments

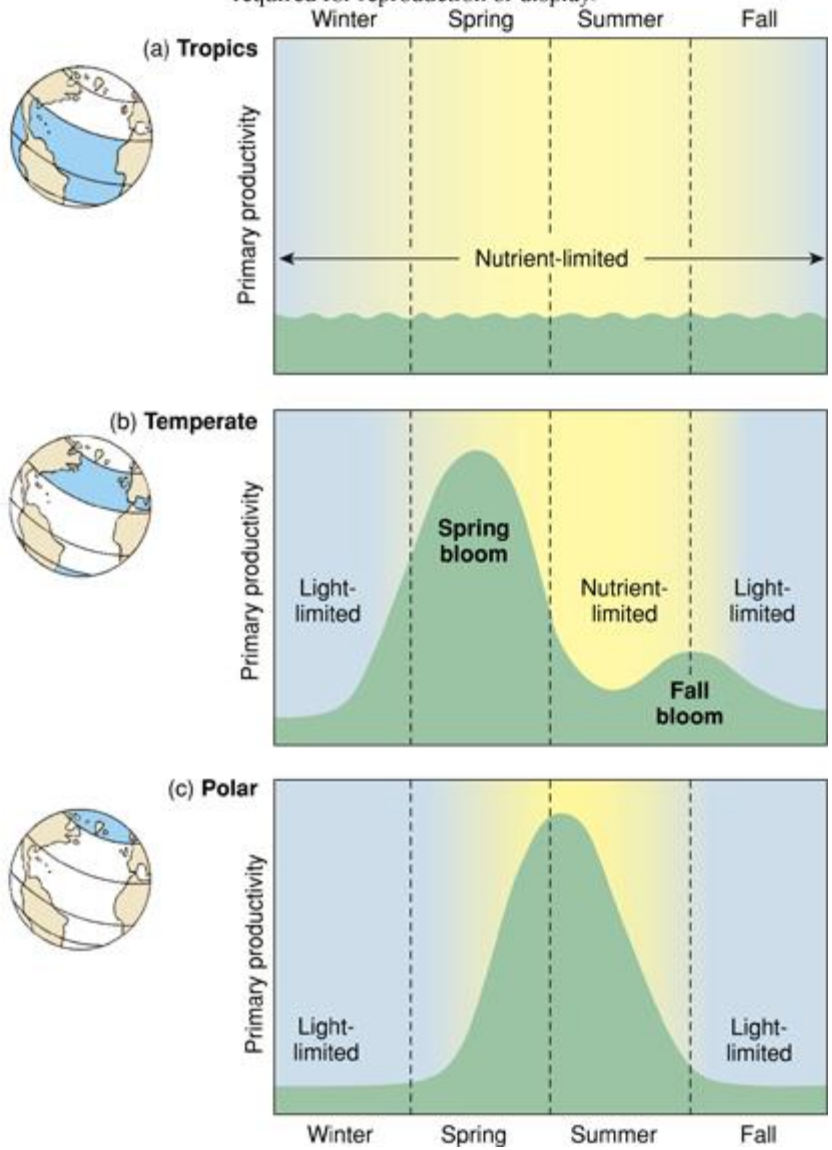
Environment	Rate of Production (Grams of Carbon Fixed/M^2/YR)
PELAGIC ENVIRONMENTS	
Arctic Ocean	<1–100
Southern Ocean (Antarctica)	40–260
Subpolar seas	50–110
Temperate seas (oceanic)	70–180
Temperate seas (coastal)	110–220
Central ocean gyres*	4–40
Equatorial upwelling areas*	70–180
Coastal upwelling areas*	110–370
BENTHIC ENVIRONMENTS	
Salt marshes	250–2,000
Mangrove forests	370–450
Seagrass beds	550–1,100
Kelp beds	640–1,800
Coral reefs	1,500–3,700
TERRESTRIAL ENVIRONMENTS	
Extreme deserts	0–4
Temperate farmlands	550–700
Tropical rain forests	460–1,600

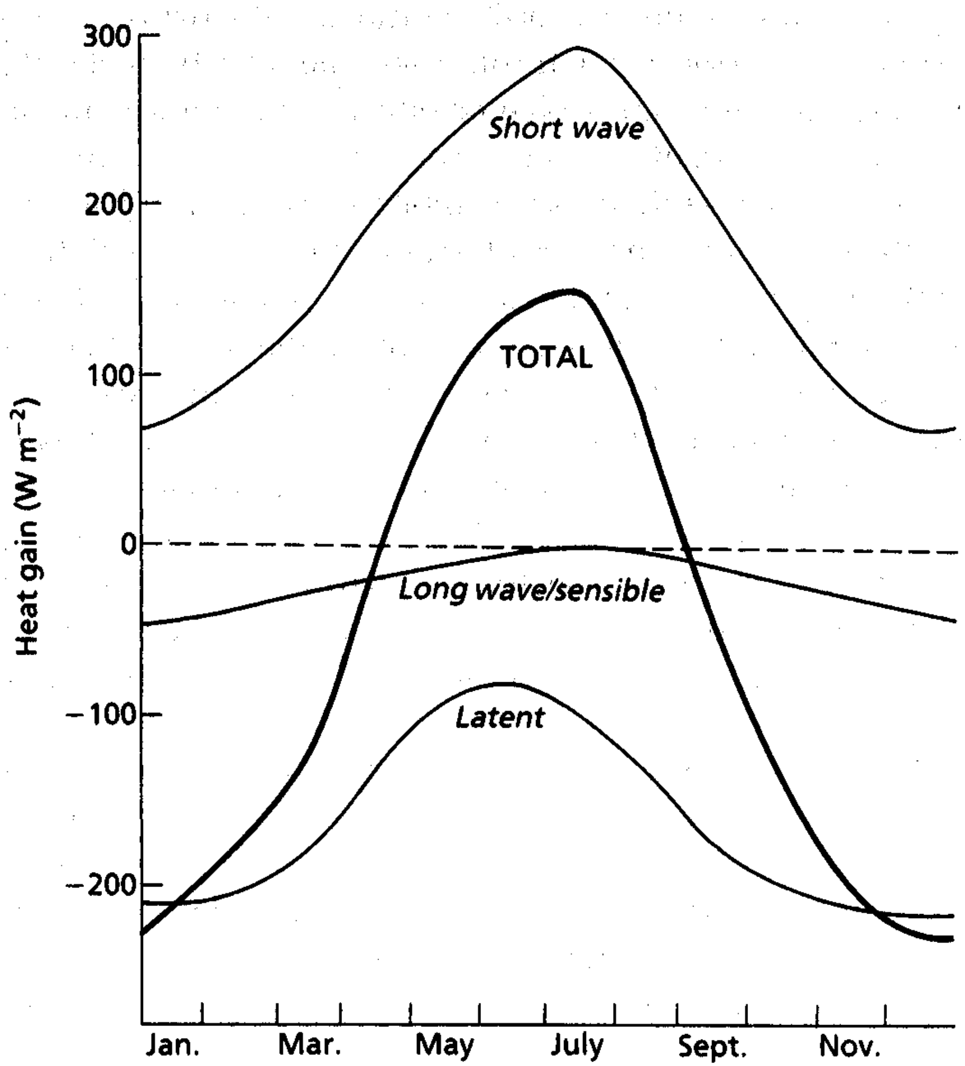
Note: Production rates can be much higher at certain times or in specific locations, especially at high latitudes. Values for some selected terrestrial environments are given for comparison.

*See "Patterns of Production," p. •••.

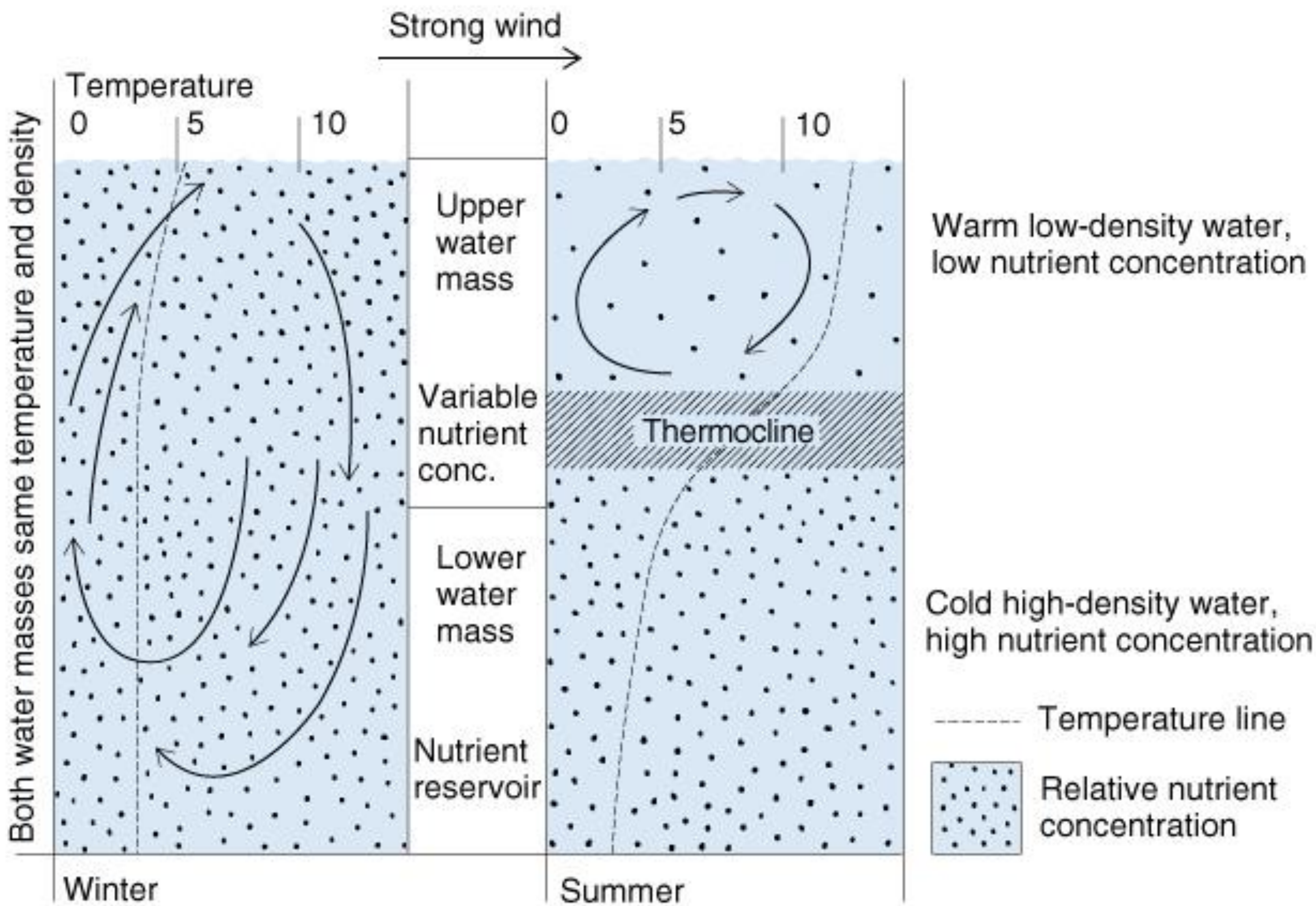
Typical primary production rates

Regions	Rates (mgC m^{-2} d^{-1})
Oligotrophic ocean	50-200
Shelves	500-2000
Coastal upwelling	2000-5000
Estuaries, Polar blooms	2000-10,000

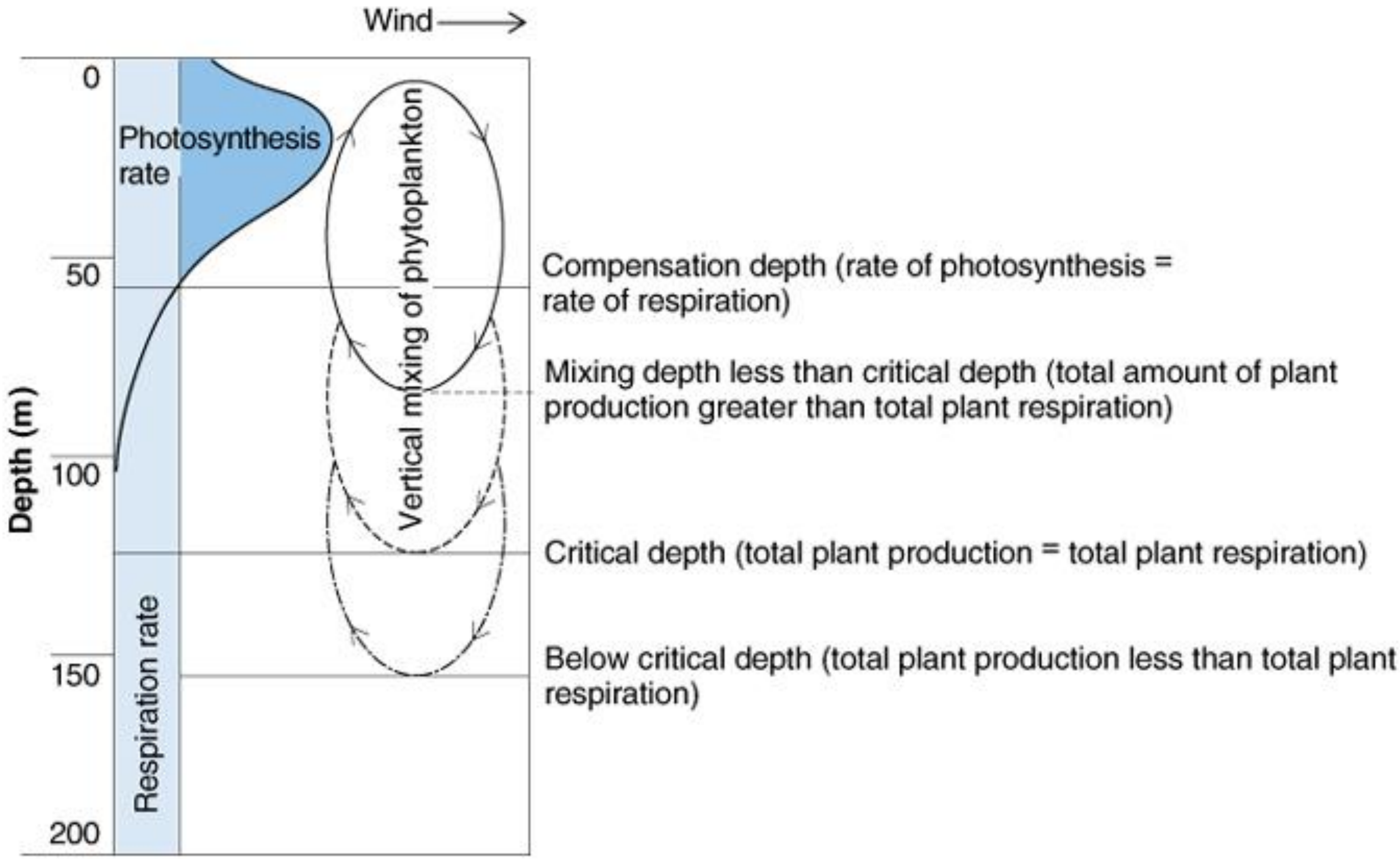

Winter
Spring
Summer
Fall
(a) Tropics
Primary productivity
Nutrient-limited
(b) Temperate
Primary productivity
Spring bloom
Light-limited
Nutrient-limited
Light-limited
Fall bloom
(c) Polar
Primary productivity
Light-limited
Light-limited
Winter
Spring
Summer
Fall



Seasonal changes in net short-wave radiation, net long-wave radiation/sensible heat exchange, and latent heat exchange, and the total at 35ºN 48ºW



Strong wind
Temperature
0
5
10
0
5
10
Upper water mass
Variable nutrient conc.
Lower water mass
Nutrient reservoir
Thermocline
Warm low-density water, low nutrient concentration
Cold high-density water, high nutrient concentration
Temperature line
Relative nutrient concentration
Both water masses same temperature and density
Winter
Summer


Wind
0
50
100
150
200
Depth (m)
Photosynthesis rate
Respiration rate
Vertical mixing of phytoplankton
Compensation depth (rate of photosynthesis = rate of respiration)
Mixing depth less than critical depth (total amount of plant production greater than total plant respiration)
Critical depth (total plant production = total plant respiration)
Below critical depth (total plant production less than total plant respiration)

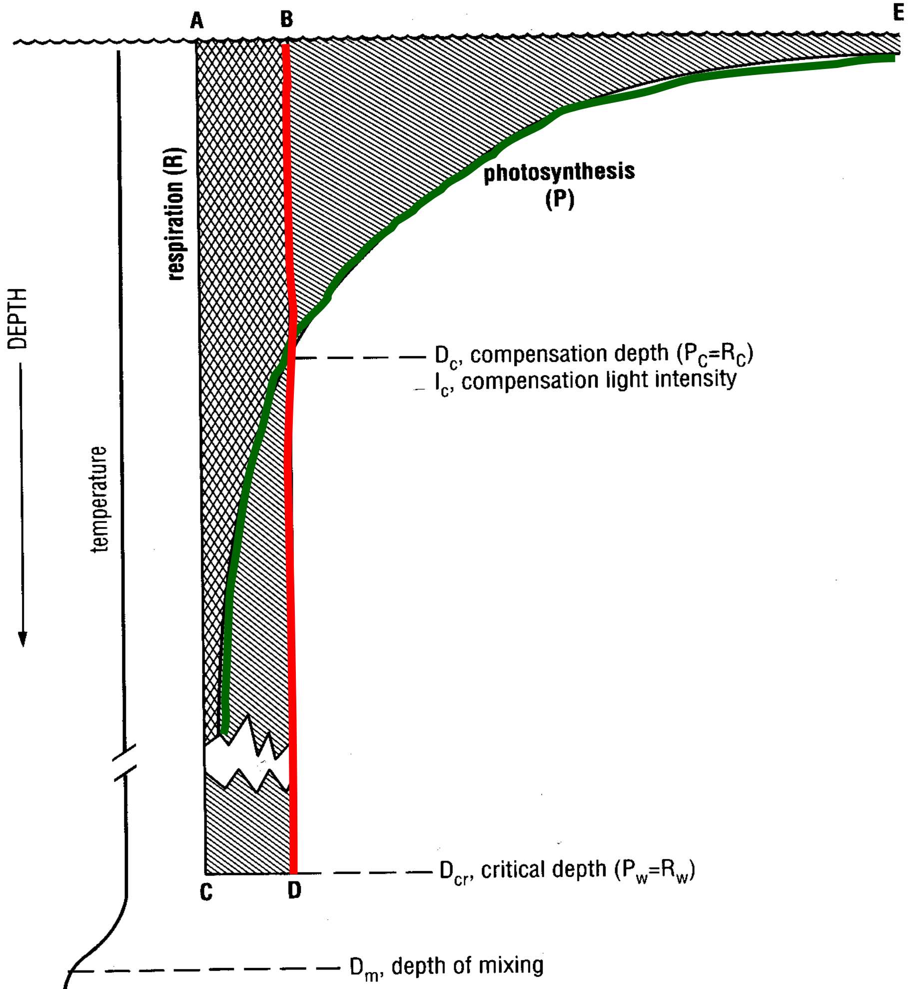


Figure 3.6 An illustration of the relationships among the compensation light depth, the critical depth, and the depth of mixing. At the compensation depth (D_c), the light intensity (I_c) is such that the photosynthesis of a single cell (P_c) is equal to its respiration (R_c); above this depth there is a net gain from photosynthesis ($P_c > R_c$) and below it there is a net loss ($P_c < R_c$). As phytoplankton cells are mixed above and below the compensation depth, they experience an average light intensity (I_D) in the water column. The depth at which I_D equals I_c is the critical depth (D_{cr}) where photosynthesis throughout the water column (P_w) equals phytoplankton respiration throughout the water column (R_w). The area bounded by points A, B, C and D represents phytoplankton respiration, and the area bounded by points A, C and E represents photosynthesis; these two areas are equal at the critical depth. When the critical depth is less than the depth of mixing (D_m) (as illustrated in this figure), no net production takes place because $P_w < R_w$. Net production of the phytoplankton ($P_w > R_w$) only occurs when the critical depth lies below the depth of mixing.

$$D_C \; : \quad P = R \; (\text{mgC m}^{-3}\ \text{d}^{-1})$$

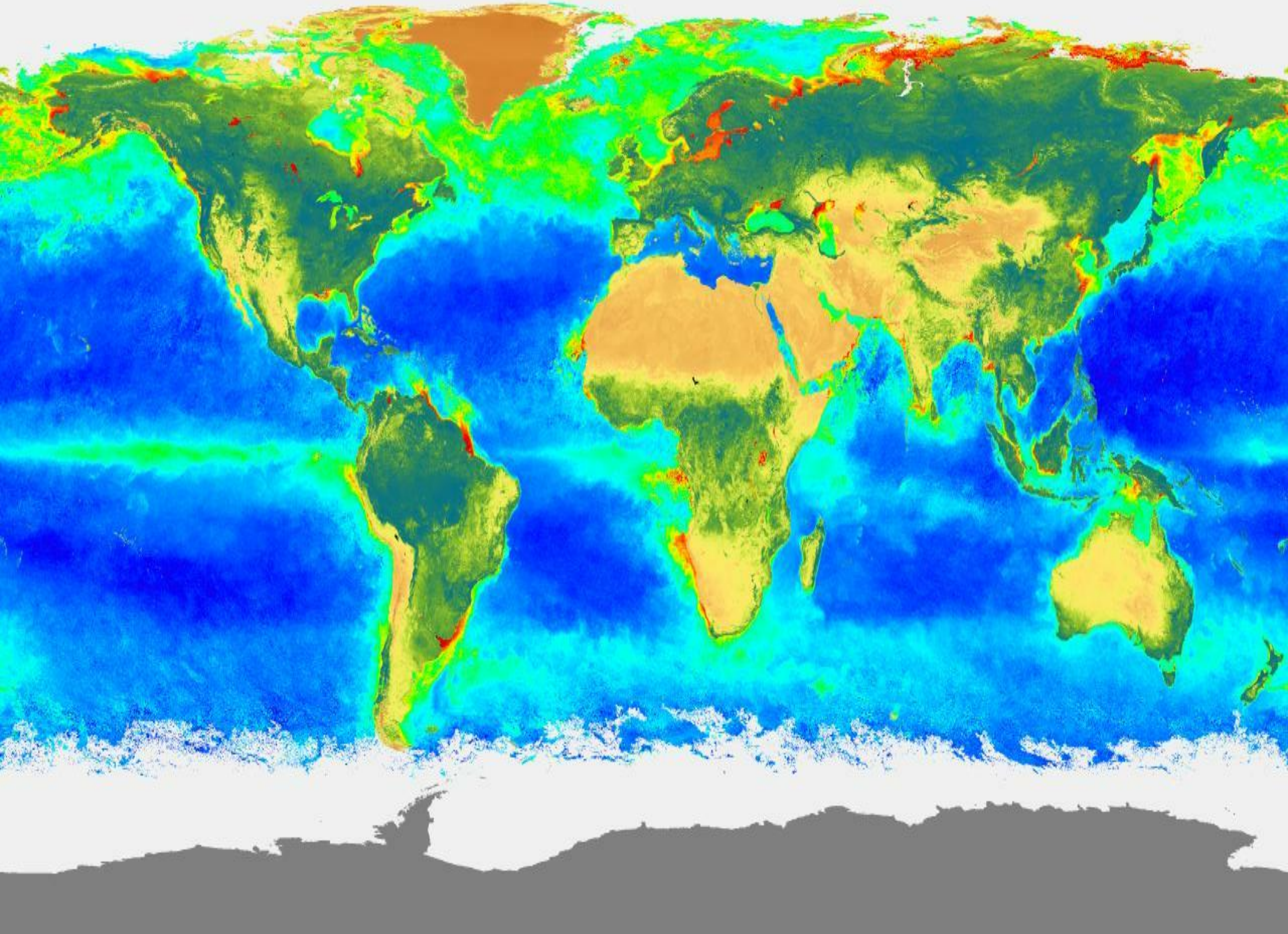
$$D_{CR} : \int P = \int R \; (\text{mgC m}^{-2}\ \text{d}^{-1})$$

$$D_m < D_{CR} \quad \rightarrow \int P > \int R$$

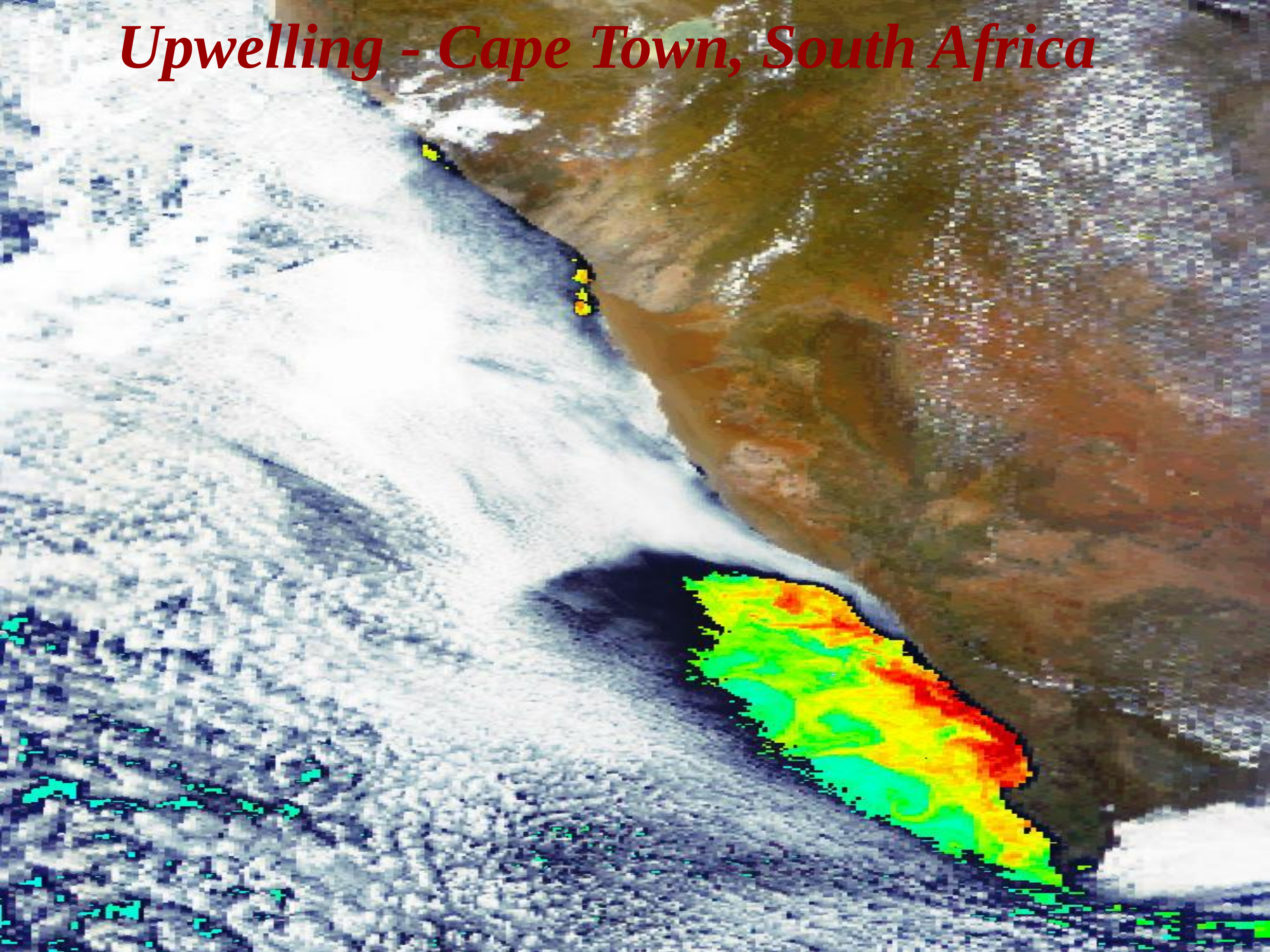
$\rightarrow$ **Bloom**

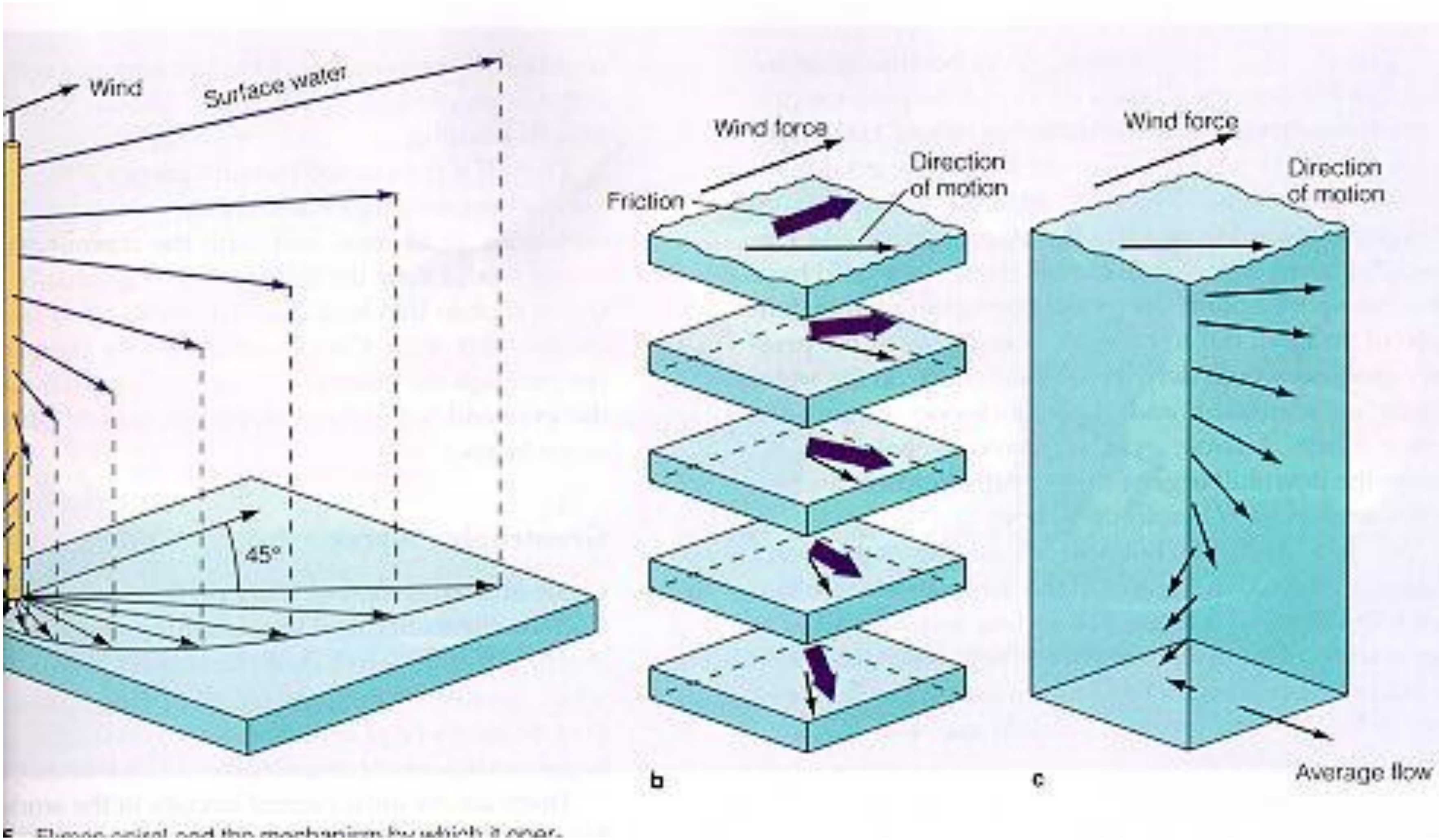
$$D_m > D_{CR} \quad \rightarrow \int P < \int R$$

$\rightarrow$ **No bloom**

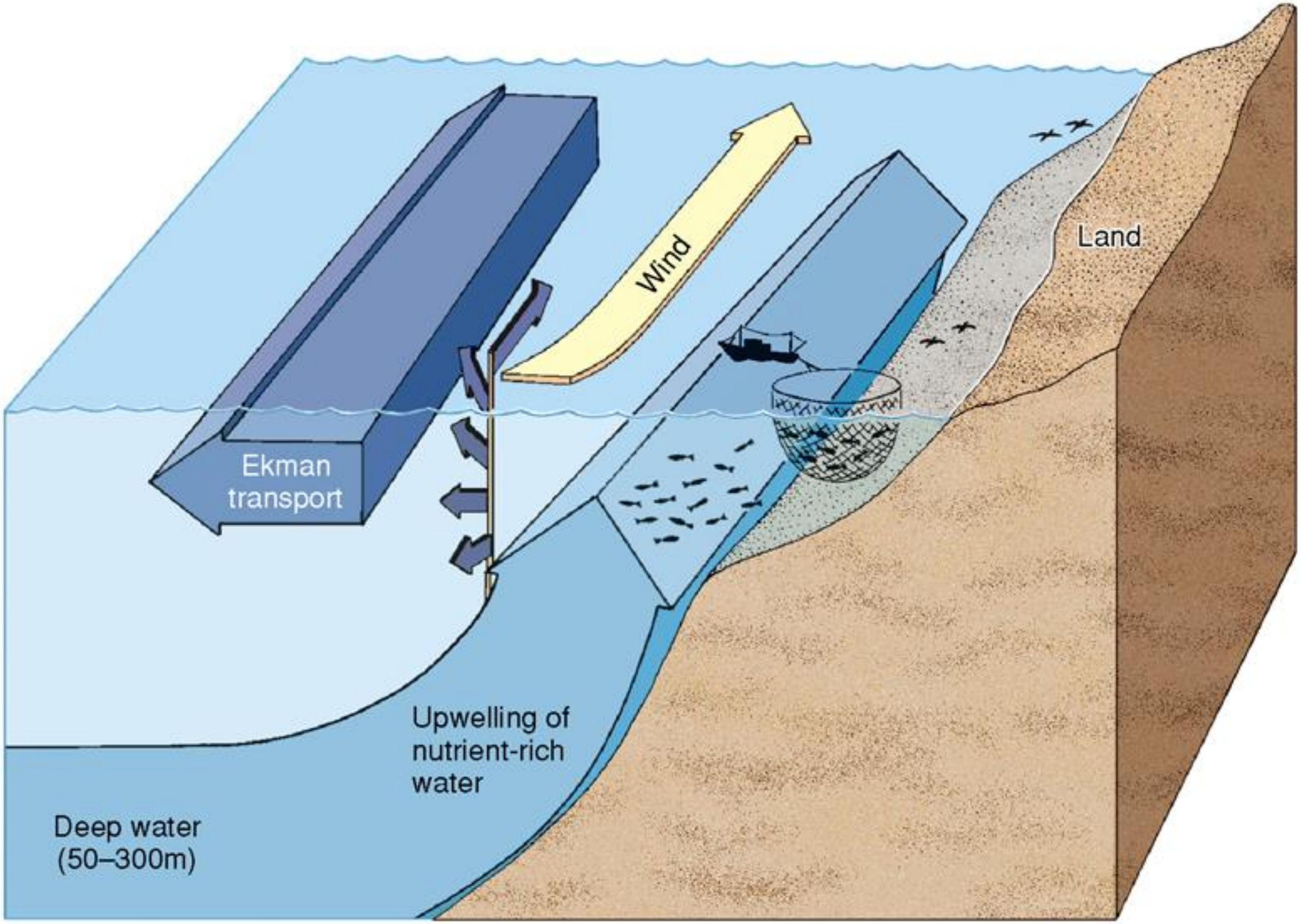


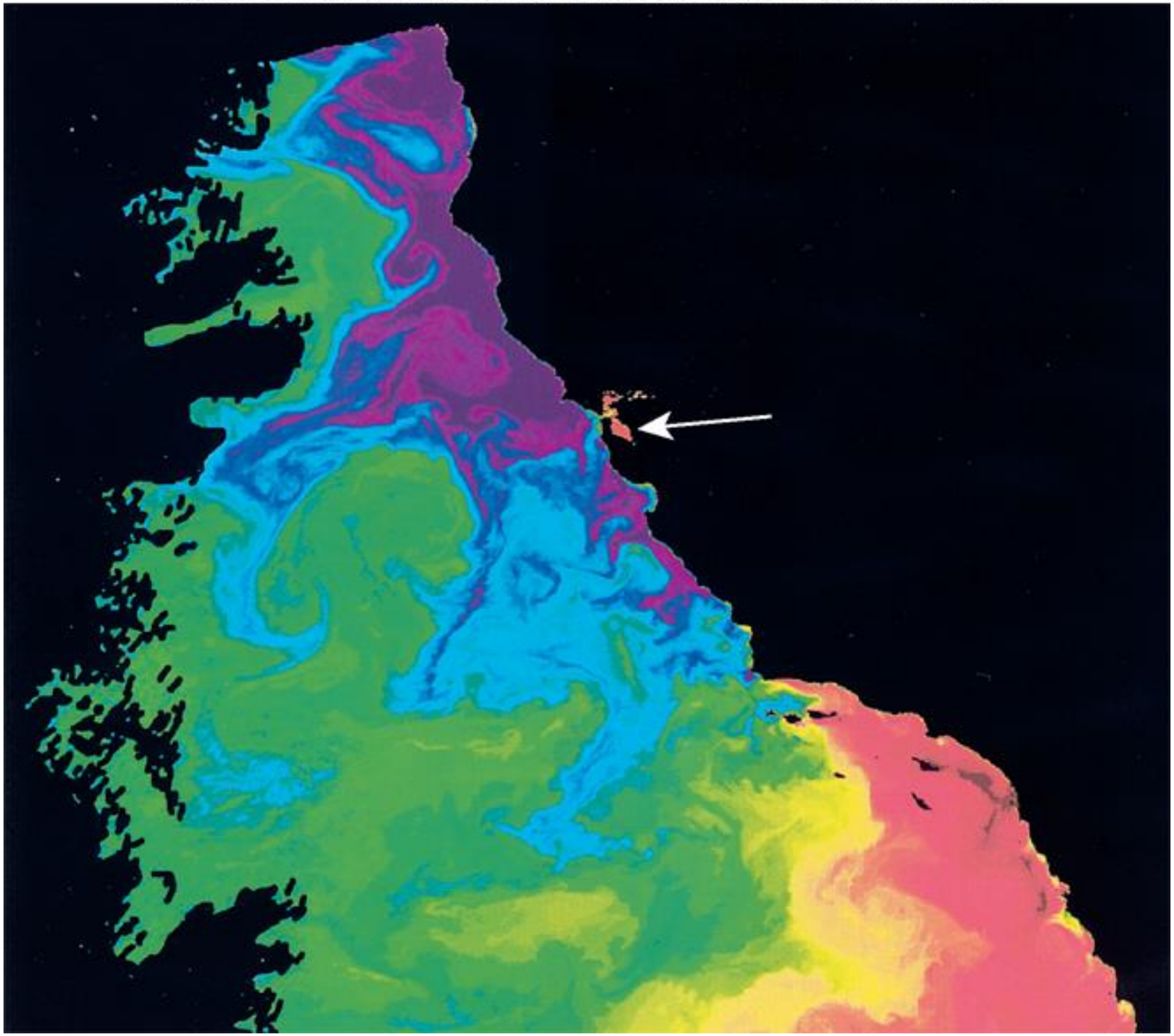
Upwelling - Cape Town, South Africa

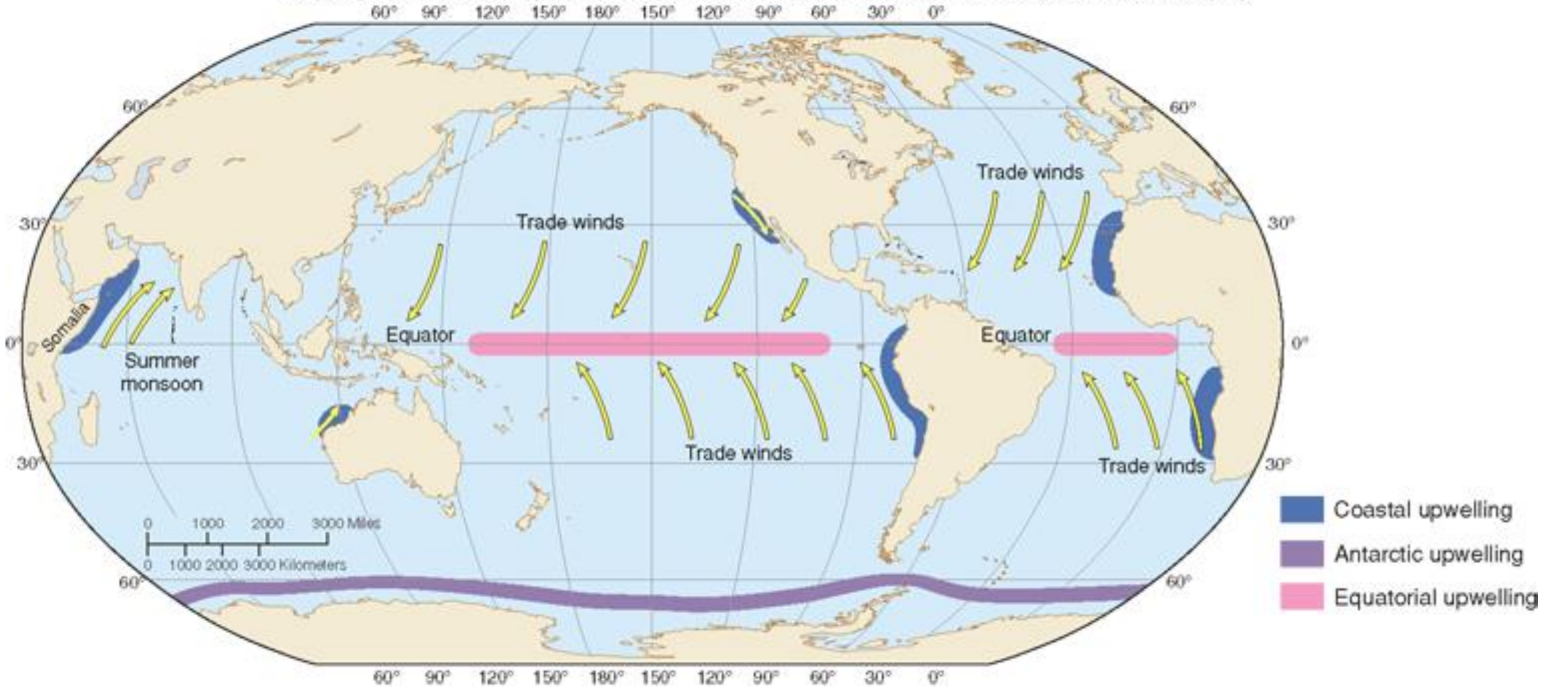


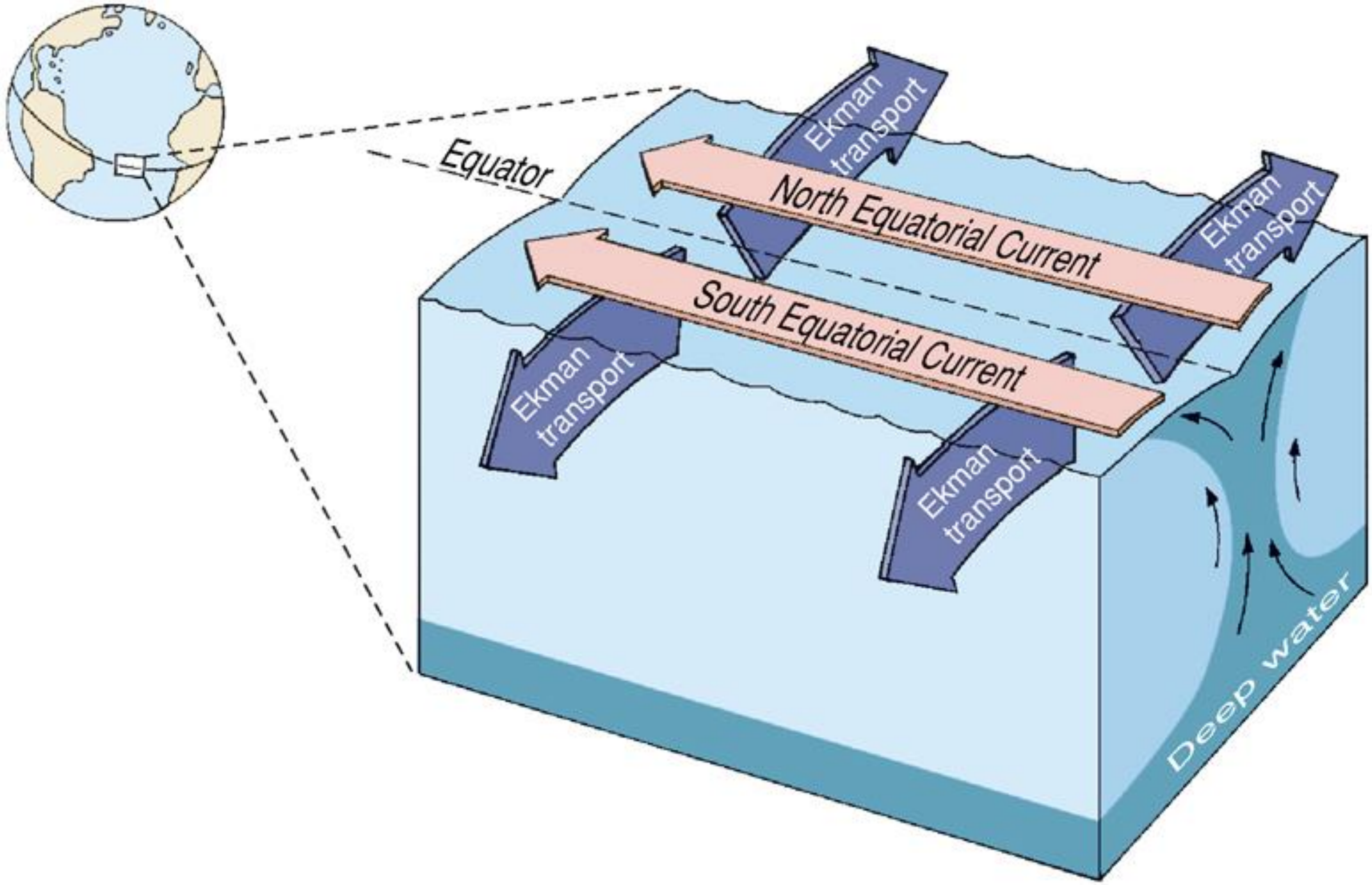


Ekman Transport

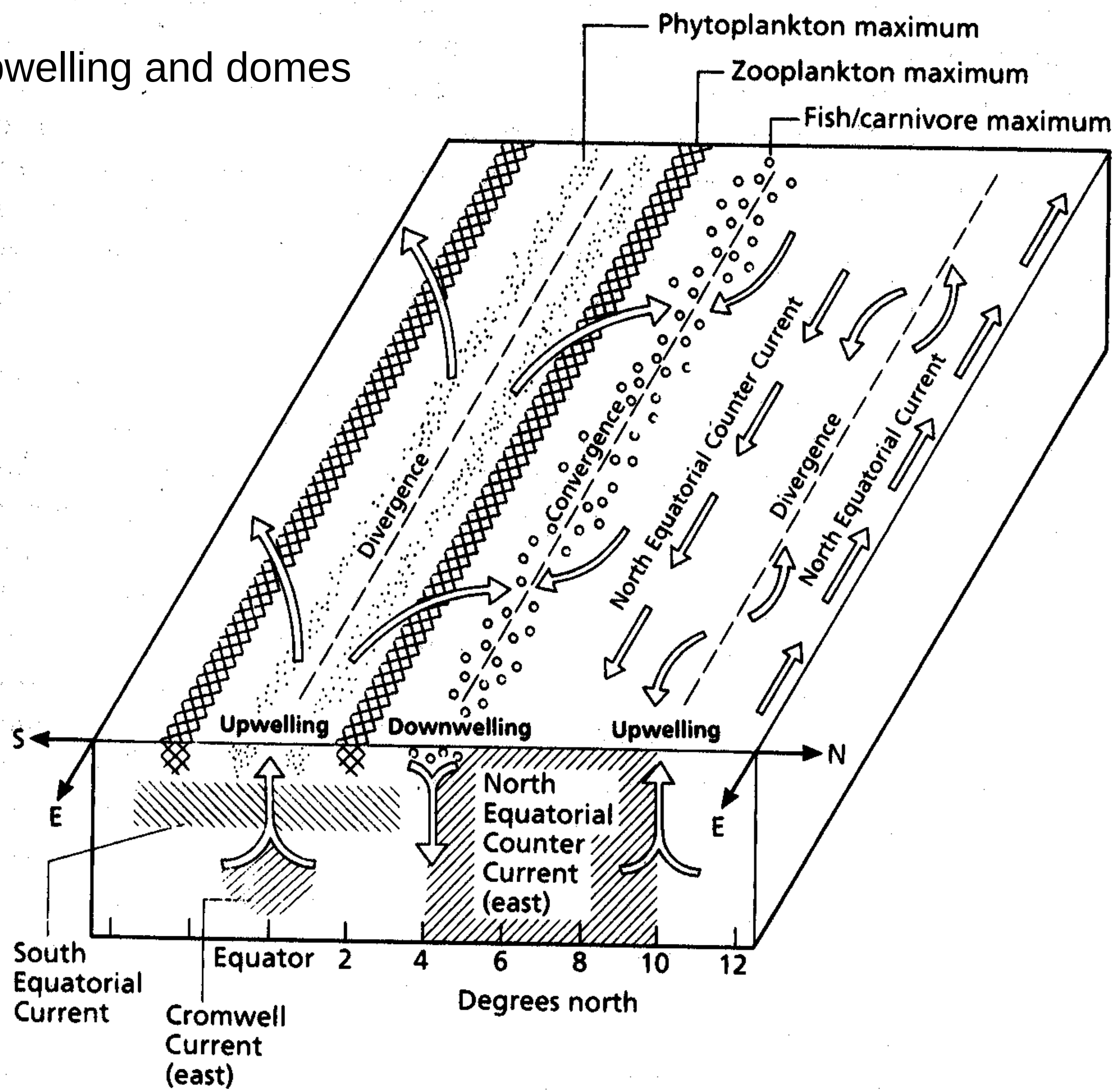

Wind
Land
Ekman transport
Upwelling of nutrient-rich water
Deep water (50–300m)

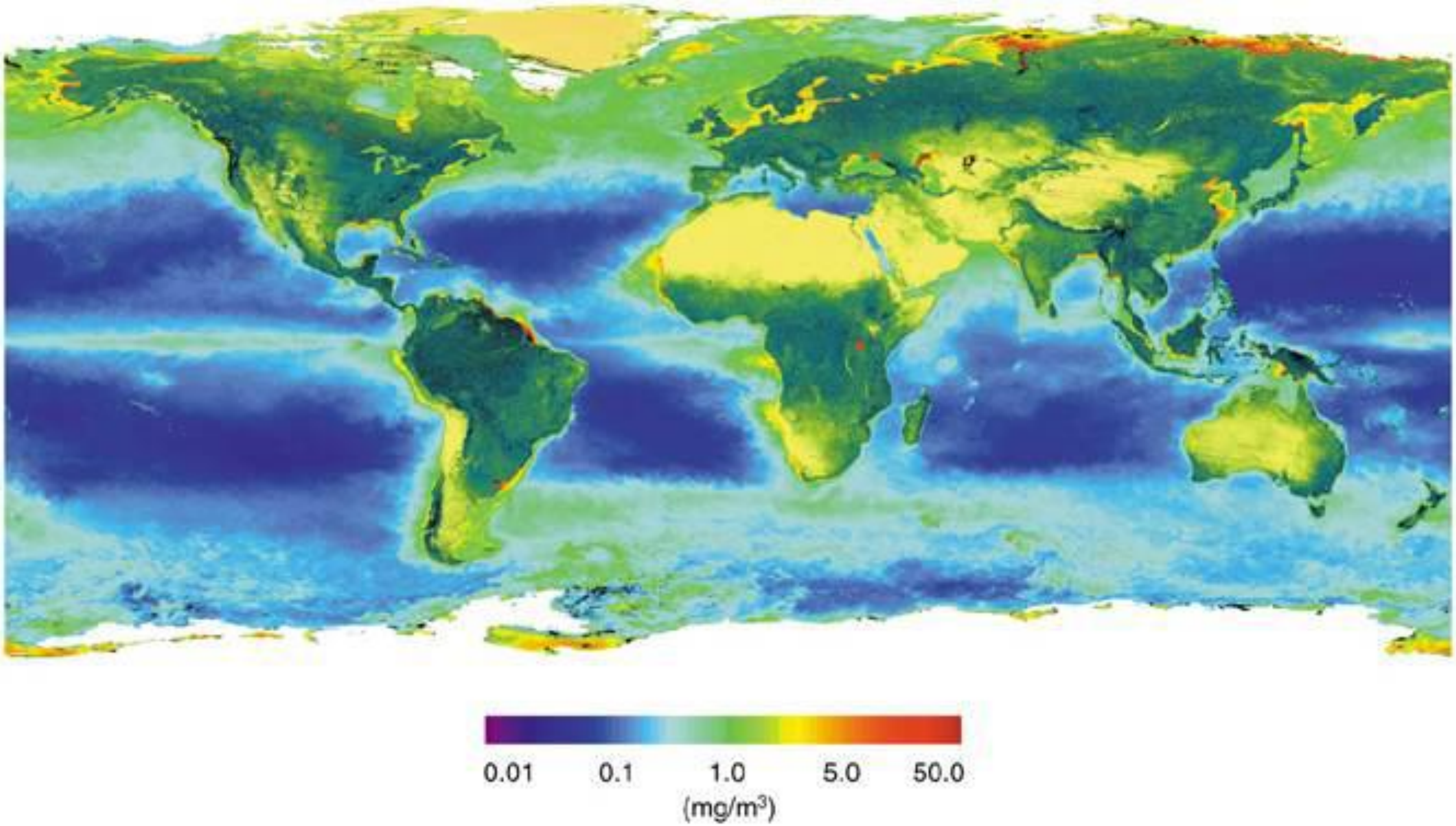



Trade winds
Trade winds
Trade winds
Trade winds
Equator
Equator
Somalia
Summer monsoon
0 1000 2000 3000 Miles
0 1000 2000 3000 Kilometers
Coastal upwelling
Antarctic upwelling
Equatorial upwelling


Equator
Ekman transport
North Equatorial Current
South Equatorial Current
Ekman transport
Ekman transport
Ekman transport
Deep water

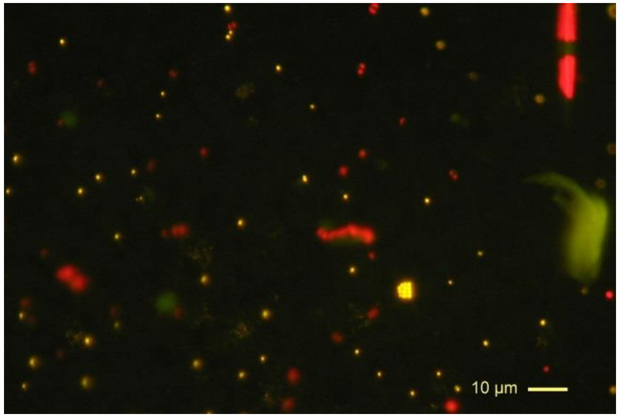
Equatorial upwelling and domes




0.01
0.1
1.0
5.0
50.0
(mg/m³)

Estuarine and coastal sea

Open ocean



Eutrophic

High production

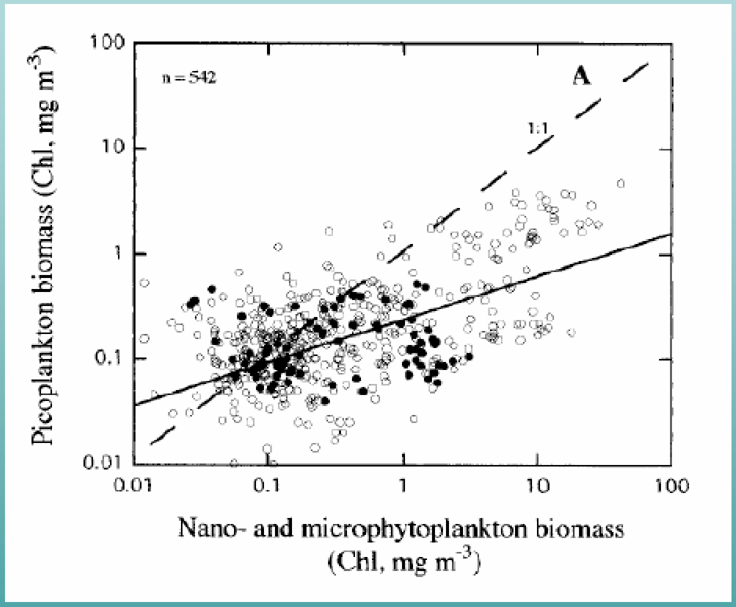
Large cells (microplankton) dominant

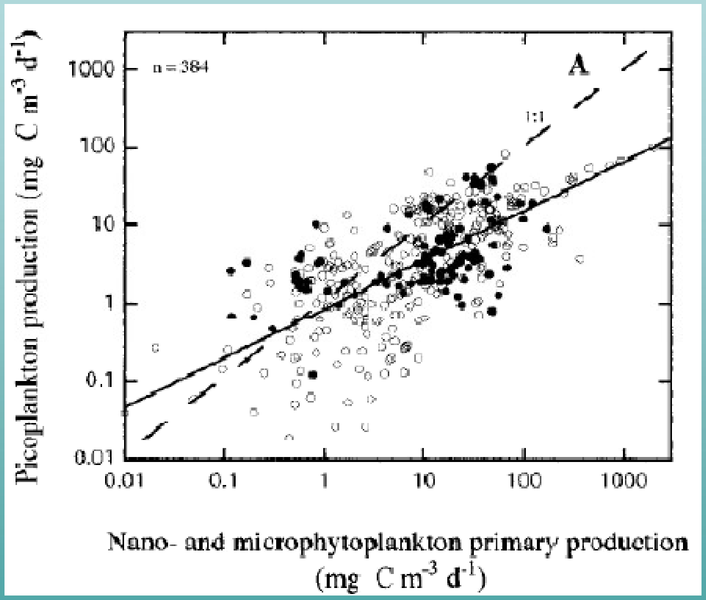
Oligotrophic

Low production

Small cells (picoplankton) dominant

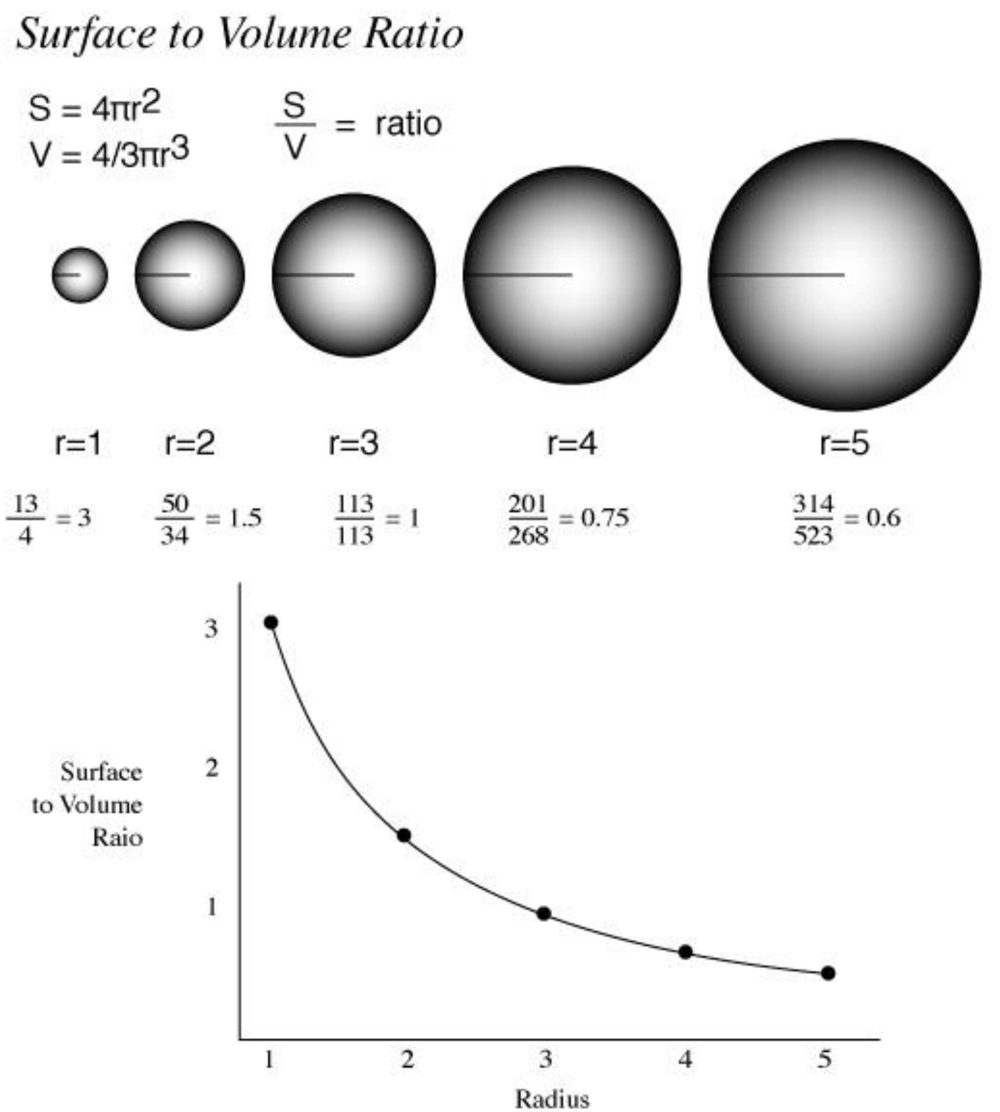
Picoplankton versus nano- and microphytoplankton biomass and production





Agawin et al., 2000

- **Why picophytoplankton dominate in oligotrophic oceanic waters?**



As a cell increases in size, the *volume* increases at a greater rate than the *surface area*. This will have profound functional consequences for the cell. Since nutrients and gas exchange must occur accross the cell membrane, an increase in size will result in a reduction of exchange functions per a unit volume. Eventually, the size will become so large that exchange across the membrane will be inadequate to support life. For this reason, cell size is "small" and cannot increase.

The smaller the cell, the larger surface-to-volume ratio……

Consequently, the larger surface-to-volume ratio, the higher diffusive rate for a given volume.

So small cell has competitive advantages in low nutrient environment.