Measuring Primary Production From Space

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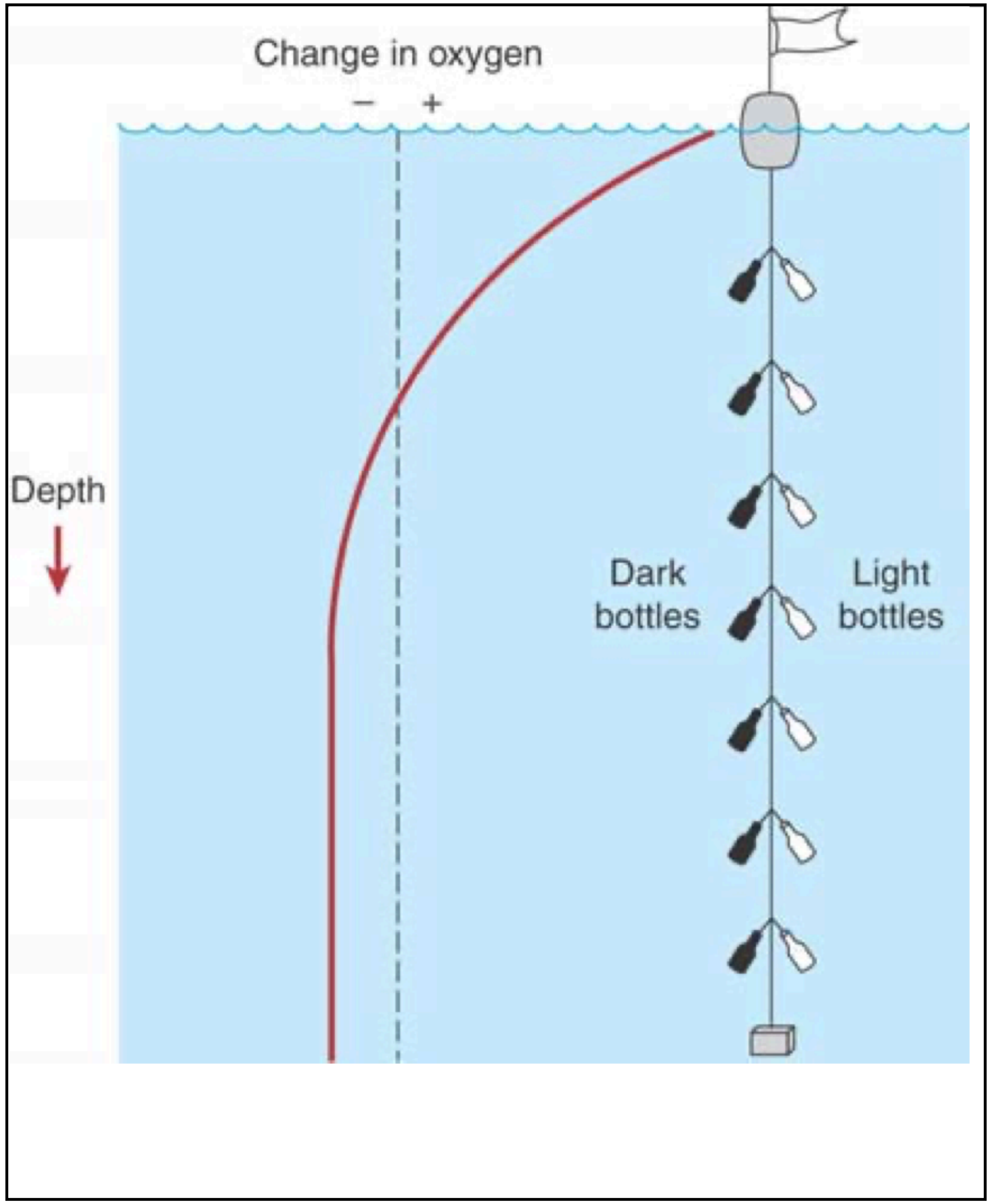
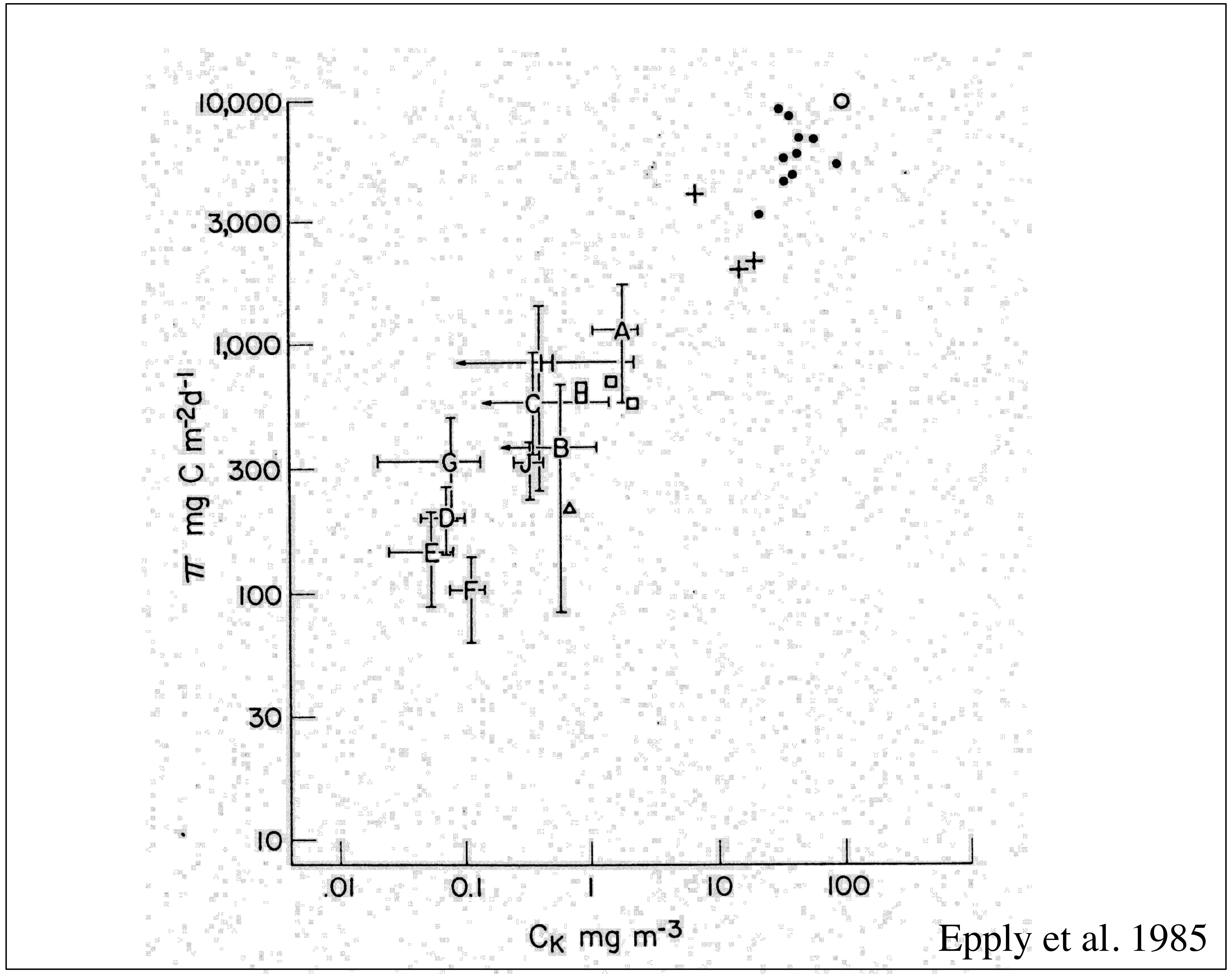
Measuring In Situ Net Primary Production

1. Seawater samples are collected at discrete depths evenly spaced down to the base of the euphoric zone.
2. Seawater samples from each depth are placed in "Light" and "Dark" bottle pairs and trace amounts of $^{14}CO_2$ are added to each bottle.
3. Bottles are put on a floating array at the depth from from which the seawater was originally collected.
4. The floating array is retrieved after 24hr incubation.
5. Seawater samples are passed through 0.2μm filter and the filter is analyzed for the amount of particulate ^{14}C retained on the filter.
6. The amount of particulate ^{14}C retained in the "Dark Bottle" is subtracted from amount of particulate ^{14}C retained in the "Light Bottle". **And then converted to NPP (mg C m^{-3} d^{-1}).**
7. In a final step all NPP measurements for each bottle are **vertically integrated** to give "Integrated Primary Production" mg C **m^{-2}** d^{-1}).



Empirical Relationship Between Surface Chlorophyll Concentration and Integrated Primary Production (Epply et al. 1985)

Net Primary Production
Integrated Over the Euphotic Zone

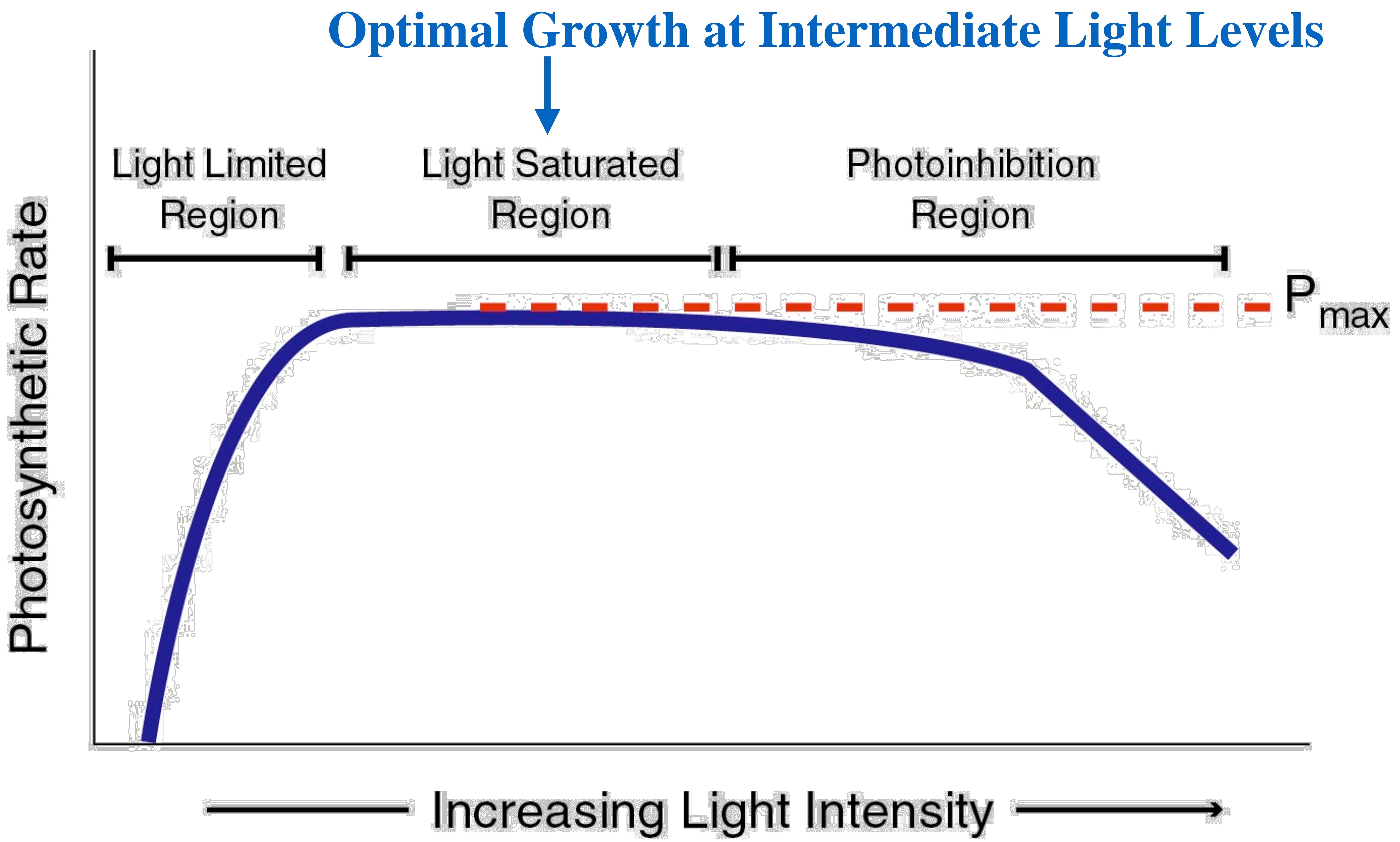


Surface Chlorophyll Concentration

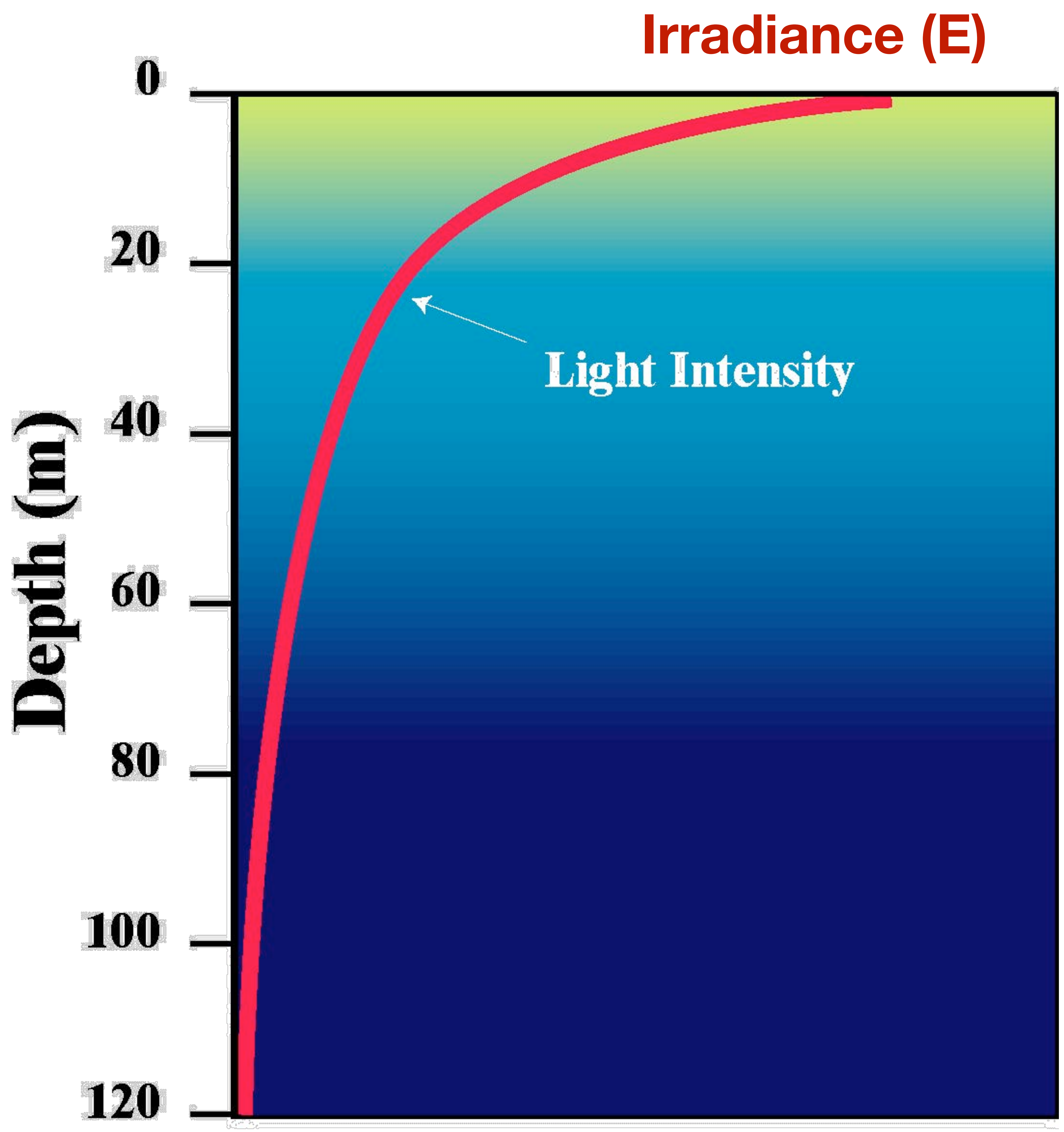
Behrenfeld and Falkowski (1997) Model of Net Primary Production (NPP)

But First Some Background…

Photosynthetic Rate Versus Light Intensity



Vertical Distribution of Light in the Ocean

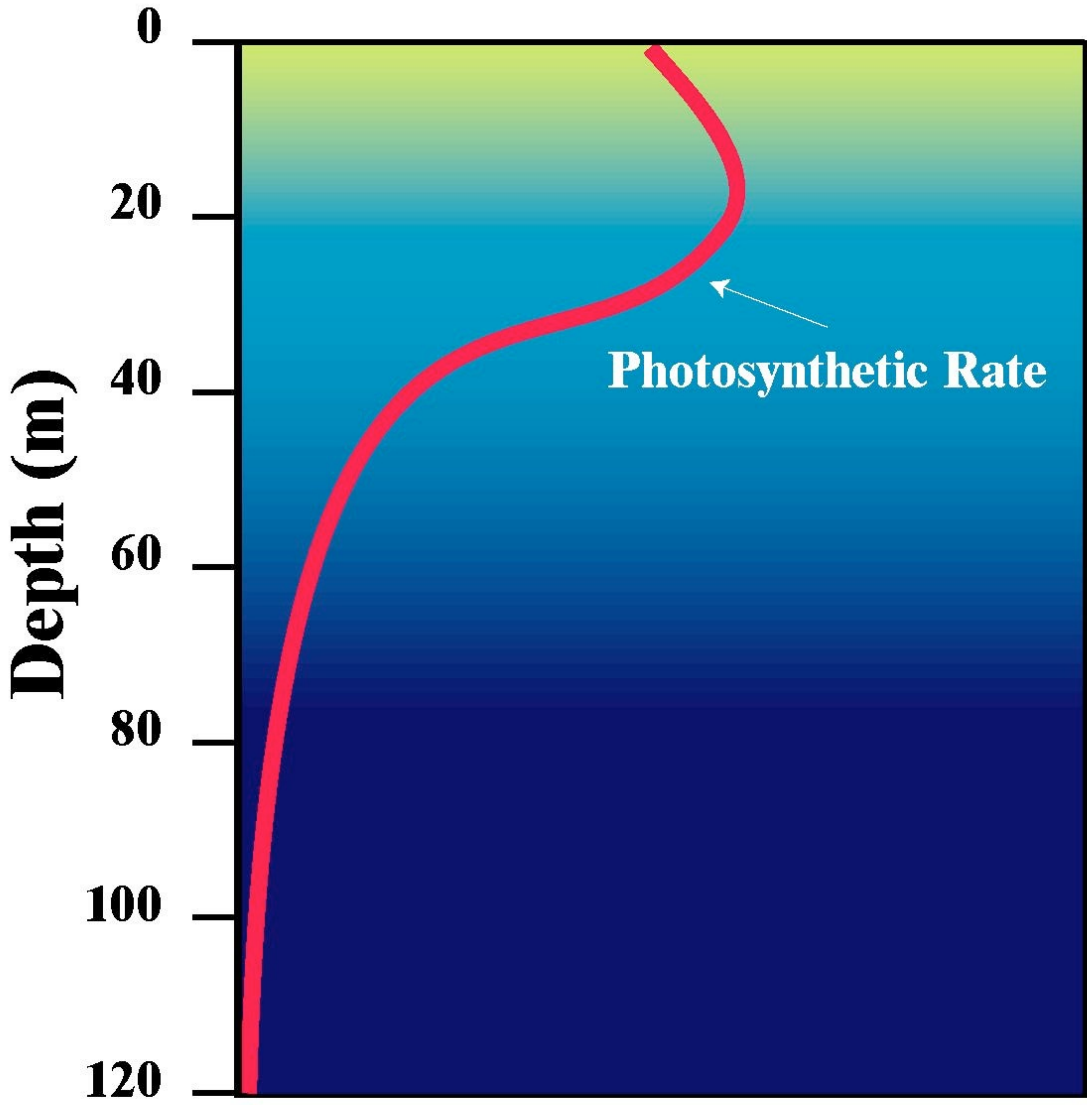


Light Intensity Decays Exponentially With Depth

$E = E_o e^{-kz}$

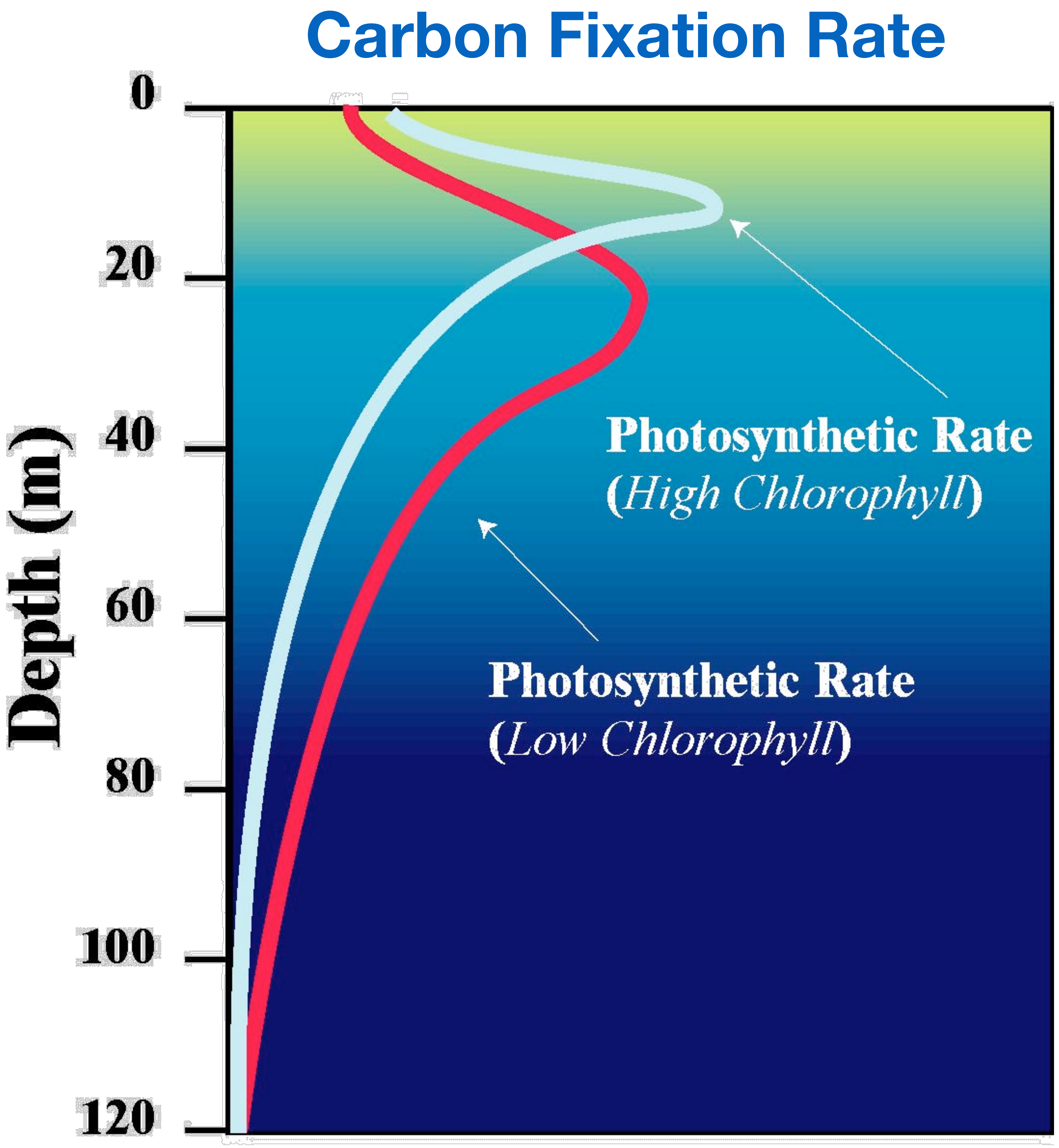
Note 1: One **optical depth** is also known as the the **e-folding depth** or… the depth as which $k*z = 1$ to give…
$E = E_o e^{-1.0}$ (about 0.3 of surface intensity)

Note 2: Multiplying physical depth by k recasts the vertical axis from z (meters) to optical depth - **an index of light level**

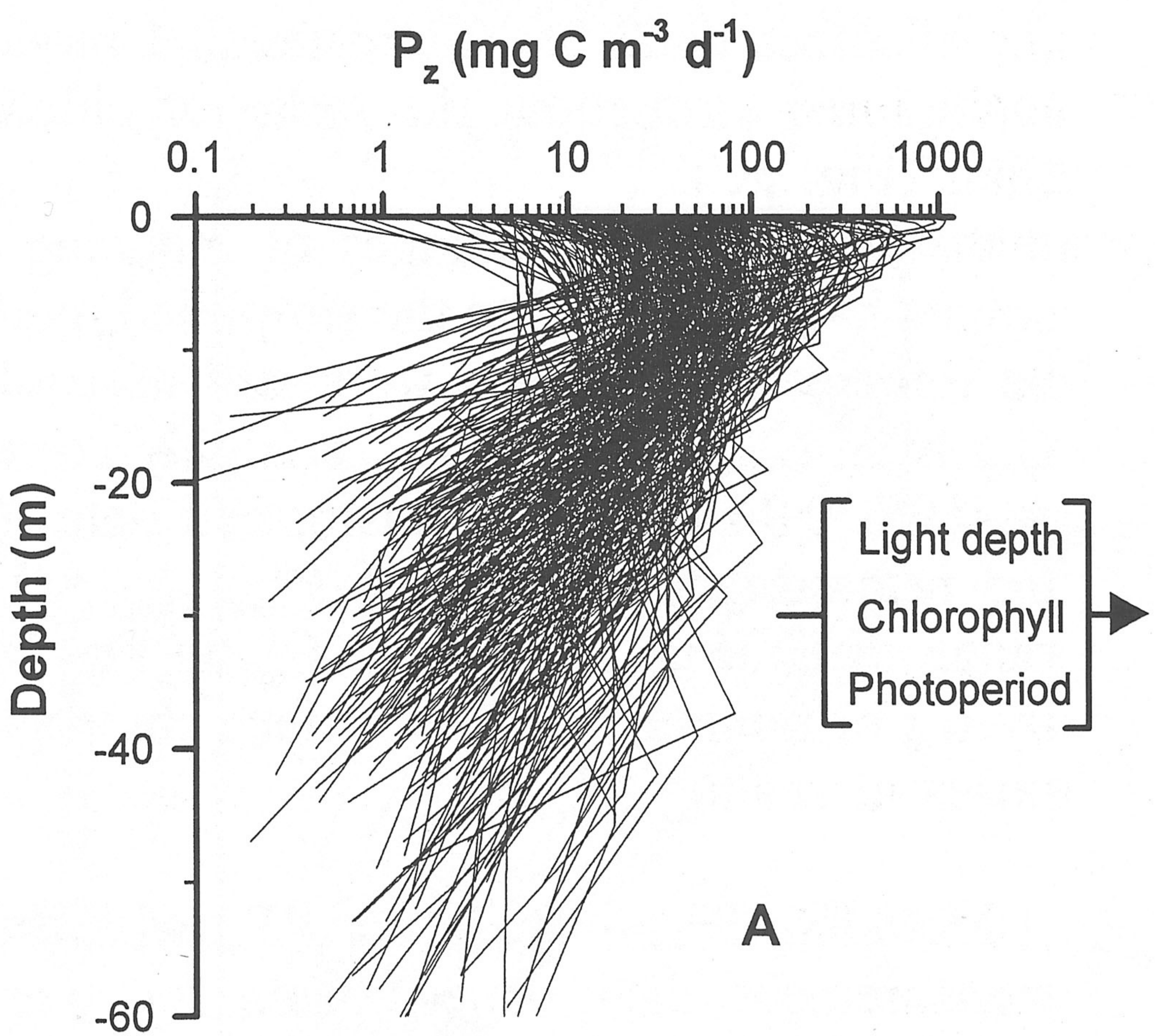


0
20
40
60
80
100
120
Depth (m)
Photosynthetic Rate

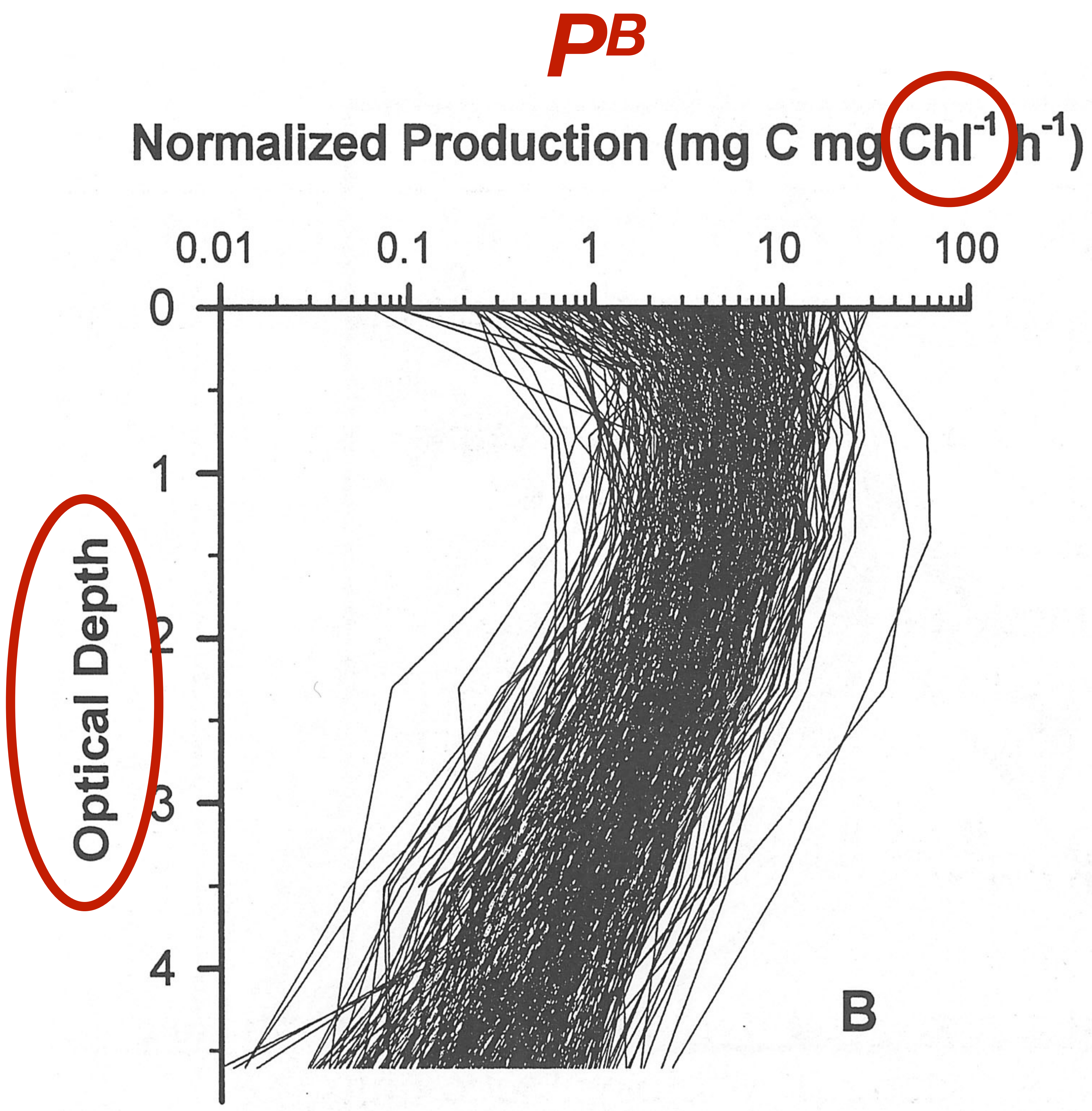
Effect of Water Clarity on Carbon Fixation Rates



Vertically Generalized Production Model (VGPM)

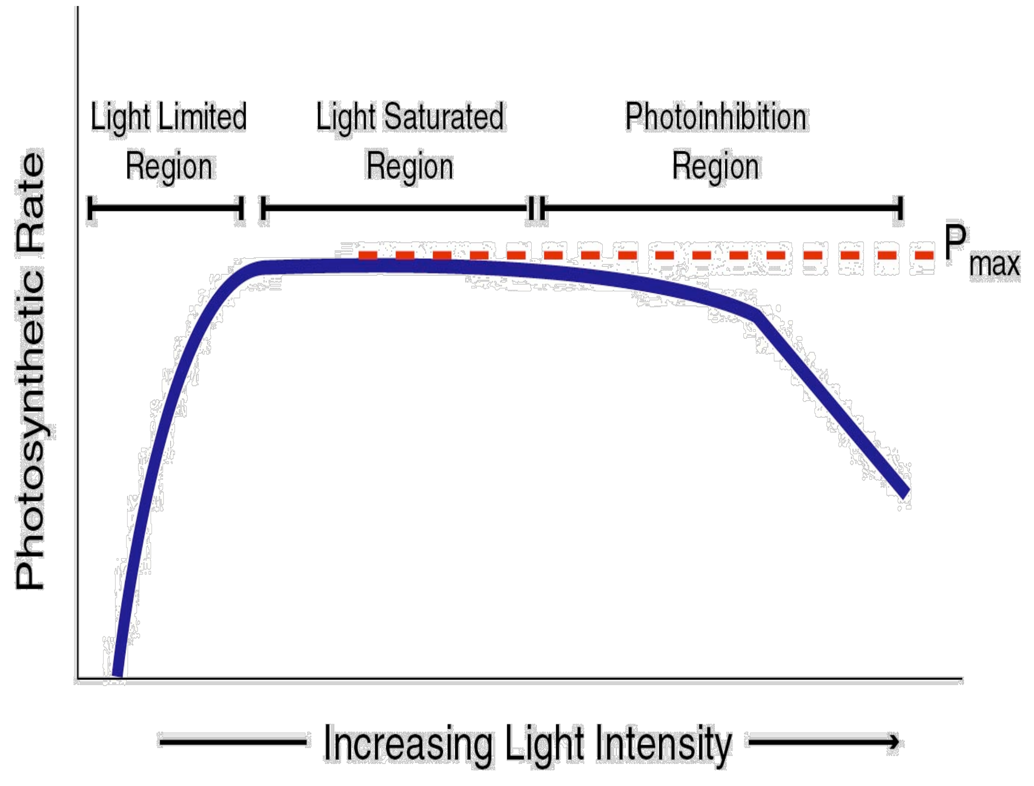


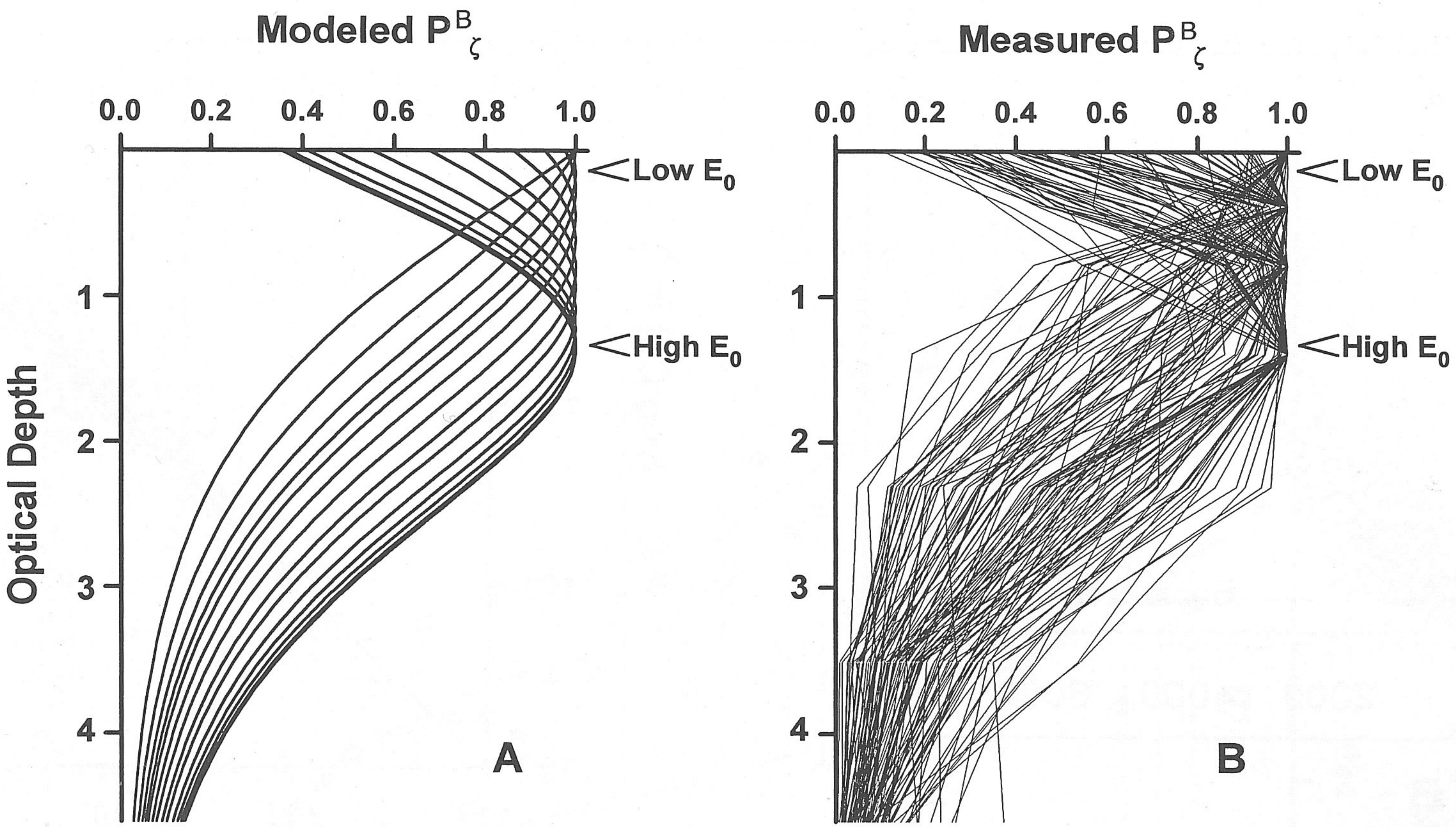
Convert to optical depth by multiplying physical depth by respective k for each profile. Note, k depends on water clarity for a given NPP cast



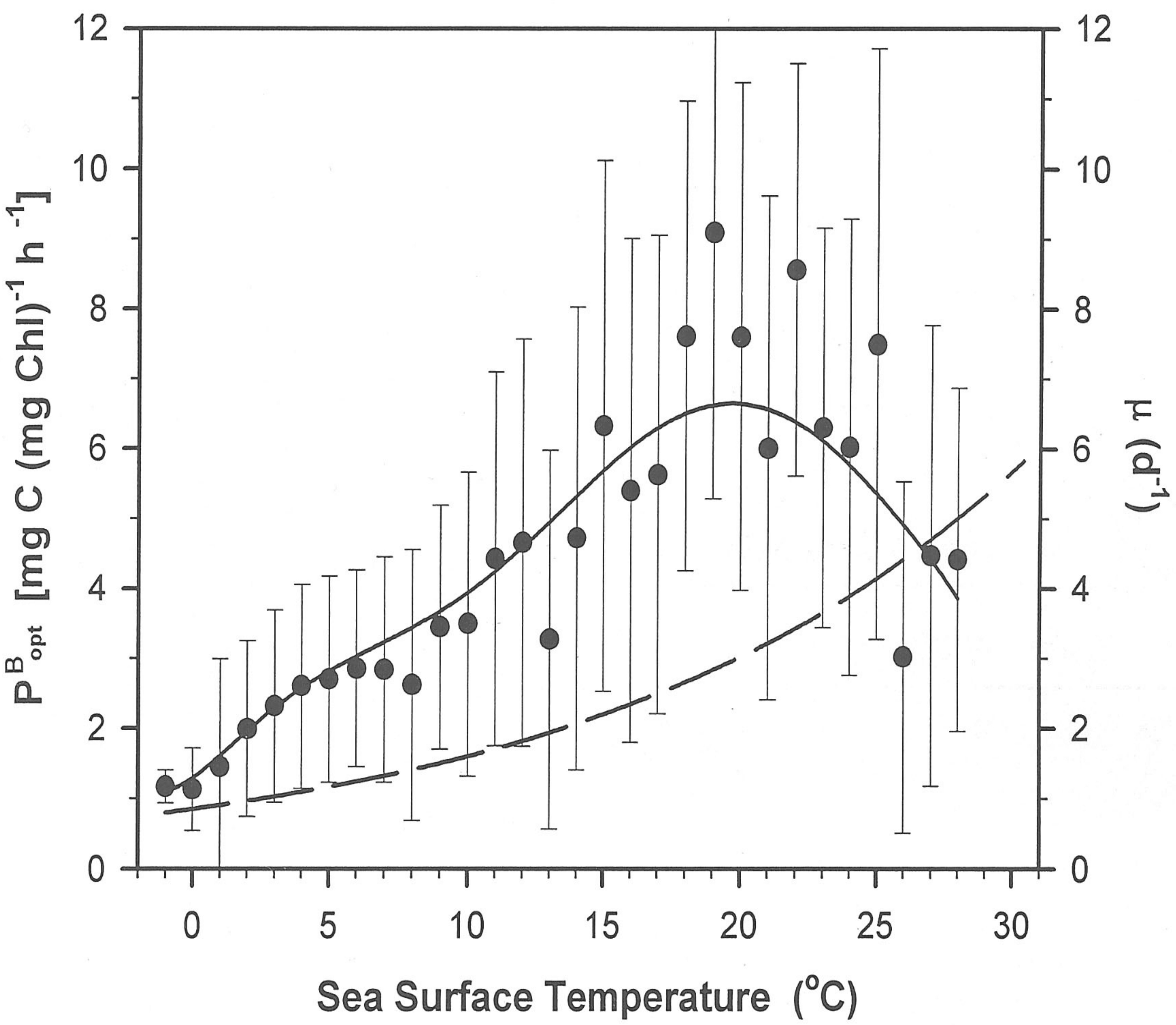
Divide P_z by Chl concentration to give an expression (P^B) that more closely resembles growth rate (**carbon fixation per unit chl**).

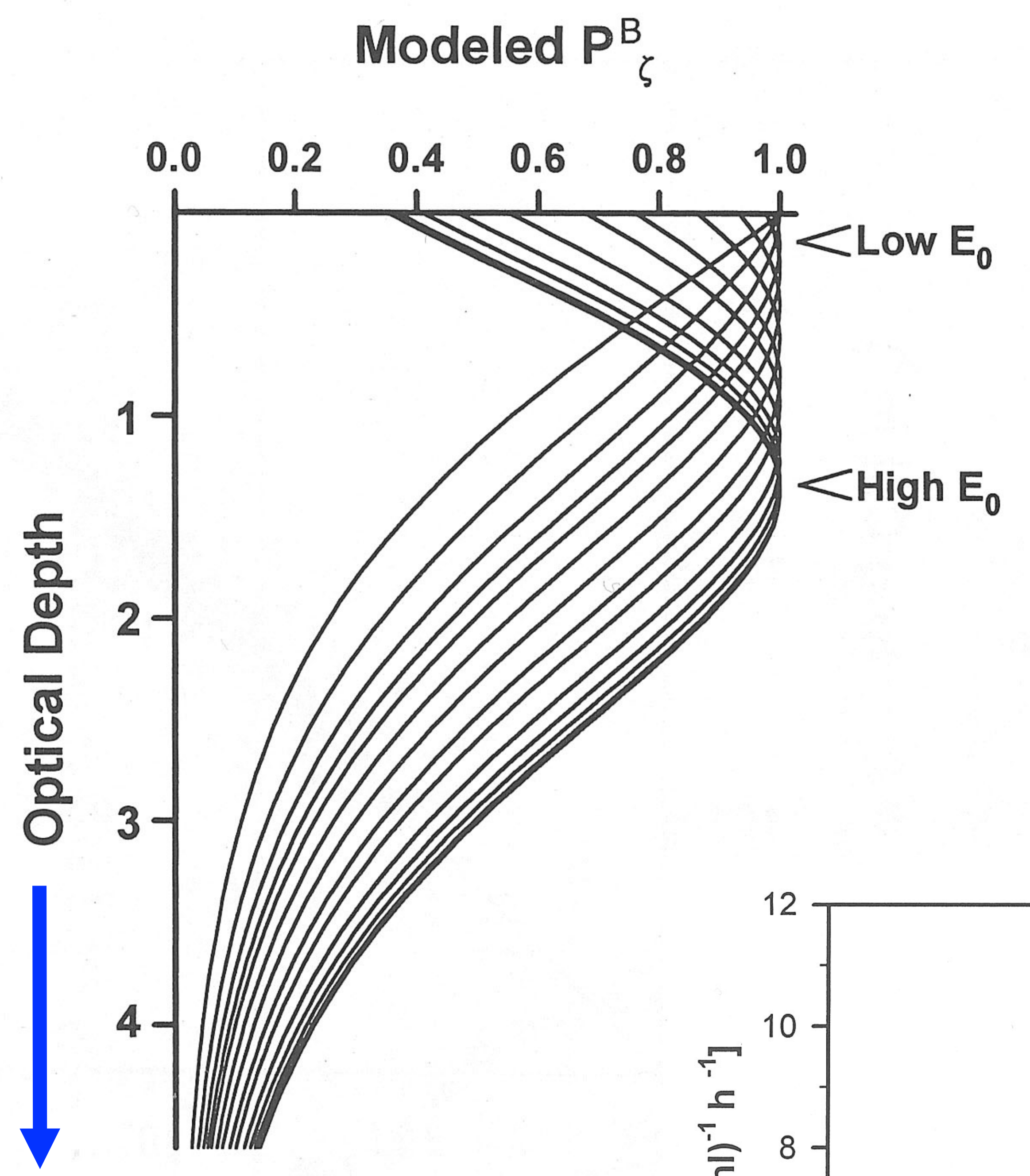
Modeled versus observed **primary production per unit chlorophyll (P^B)** curves that have been ***normalized relative to the maximum P^B value*** of each curve





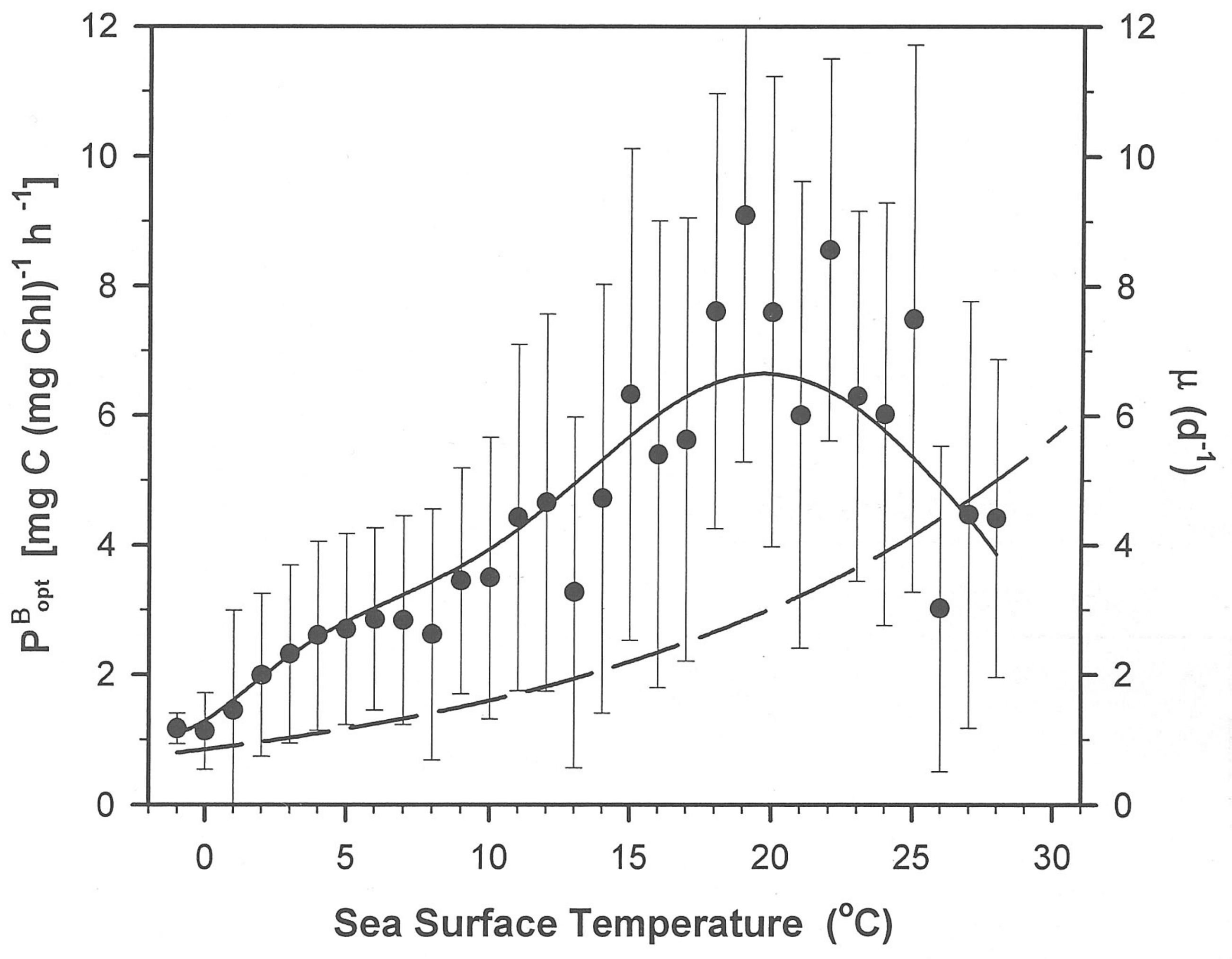
Empirical relationship between maximum P^B (**P^B_{opt}**), and corresponding sst for each respective of the npp profiles.





1. **Chlorophyll** determines **Optical Depth**

2. **E_o** (surface PAR level) determines the shape of the **normalized shape** P^B curve



3. **SST** determines the **absolute maximum P^B value**

E_o, SST and chlorophyll together determine **the *absolute* shape of the P^B curve**. All that is needed is to vertically integrate the absolute P^B * chl curve over the euphotic zone to get primary production per meter square of ocean surface.

Behrenfeld & Falkowski Model Formulation

SeaWiFS/MODIS Chl Derived

SeaWiFS/MODIS Observed

$$PP_{eu} = 0.66125 \times P_{opt}^{B} \times \left[\frac{E_0}{E_0 + 4.1} \right] \times Z_{eu} \times Chl_{opt} \times DayLen_{irr}$$

Function of SST

PAR Product Derived from SeaWiFS/MODIS

Function of Latitude and Julian Day Only

Results of Behrenfeld and Falkowski Model Averaged Individual Ocean Basins or Over Specific Trophic Regimes

Table 2. Global annual phytoplankton primary production (Pg C yr^{-1}) calculated with the vertically generalized production model (VGPM), Laboratoire de Physique et Chimie Marines (LPCM) model (Antoine et al. 1996), Bedford production model (BPM) (Longhurst et al. 1995), and the Eppley and Peterson (1979) compilation (E&P). Annual production is also shown for the five major ocean basins defined by Antoine et al. (1996) (percentages of total production indicated in parentheses), as well as three trophic categories for the VGPM and LPCM models (subpolar plus global in brackets).

	VGPM	LPCM*	BPM†	E&P‡
Global total	43.5	46.9	$50.2^{46.5}_{44.7}$	27.1
Pacific	16.7(38.3)	20.0(42.7)	$19.4^{18.1}_{17.4}$(38.6)	9.1(33.7)
Atlantic§	11.9(27.5)	11.3(24.0)	$13.7^{11.7}_{10.8}$(27.3)	8.6(31.6)
Indian	6.2(14.2)	8.1(17.3)	$6.5^{6.2}_{6.0}$(13.0)	6.0(22.0)
Arctic	0.4(0.9)	0.6(1.3)	1.4(2.8)	0.1(0.5)
Antarctic	8.3(19.1)	6.9(14.7)	9.2(18.3)	3.3(12.2)
Oligotrophic	10.3[10.5]‖	16.2		
Mesotrophic	22.0[26.4]‖	22.5		
Eutrophic	3.6[6.6]‖	2.5		

Carbon-based ocean productivity and phytoplankton physiology from space

Behrenfeld et al. (2005)

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1. Use Garver-Siegel-Maritorrena (2002) Semi-Analytical Pigment Algorithm to estimate:
   - **phytoplankton chlorophyll** concentration (from a_{ph})
   - $b_b(\lambda)$ backscattering by particulate organic matter (POC)
2. Assume a fixed ratio of phytoplankton carbon to POC based on previous published data to finally get **phytoplankton carbon**
3. Use phytoplankton **carbon:chlorophyll ratio to estimate specific growth** (μ) rate based on previously published relationships from laboratory and field measurements

For more information on Mike's Carbon-based Primary Productivity Model (CbPM) - including all of his global data products - See:

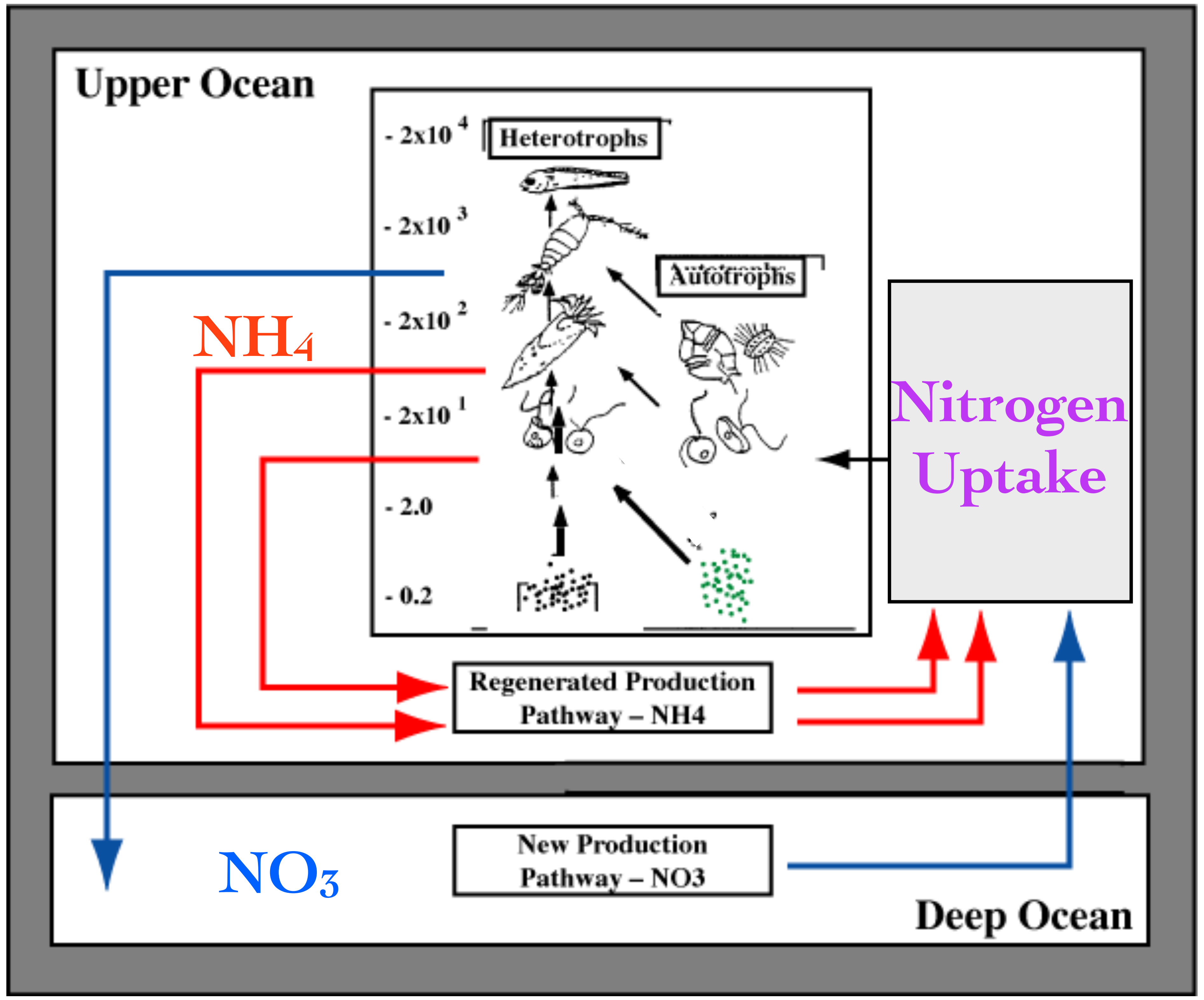
http://www.science.oregonstate.edu/ocean.productivity/

Total Primary Production versus Export Production

Satellite-Derived Primary Production Algorithms Estimate ***Total*** Primary Production.

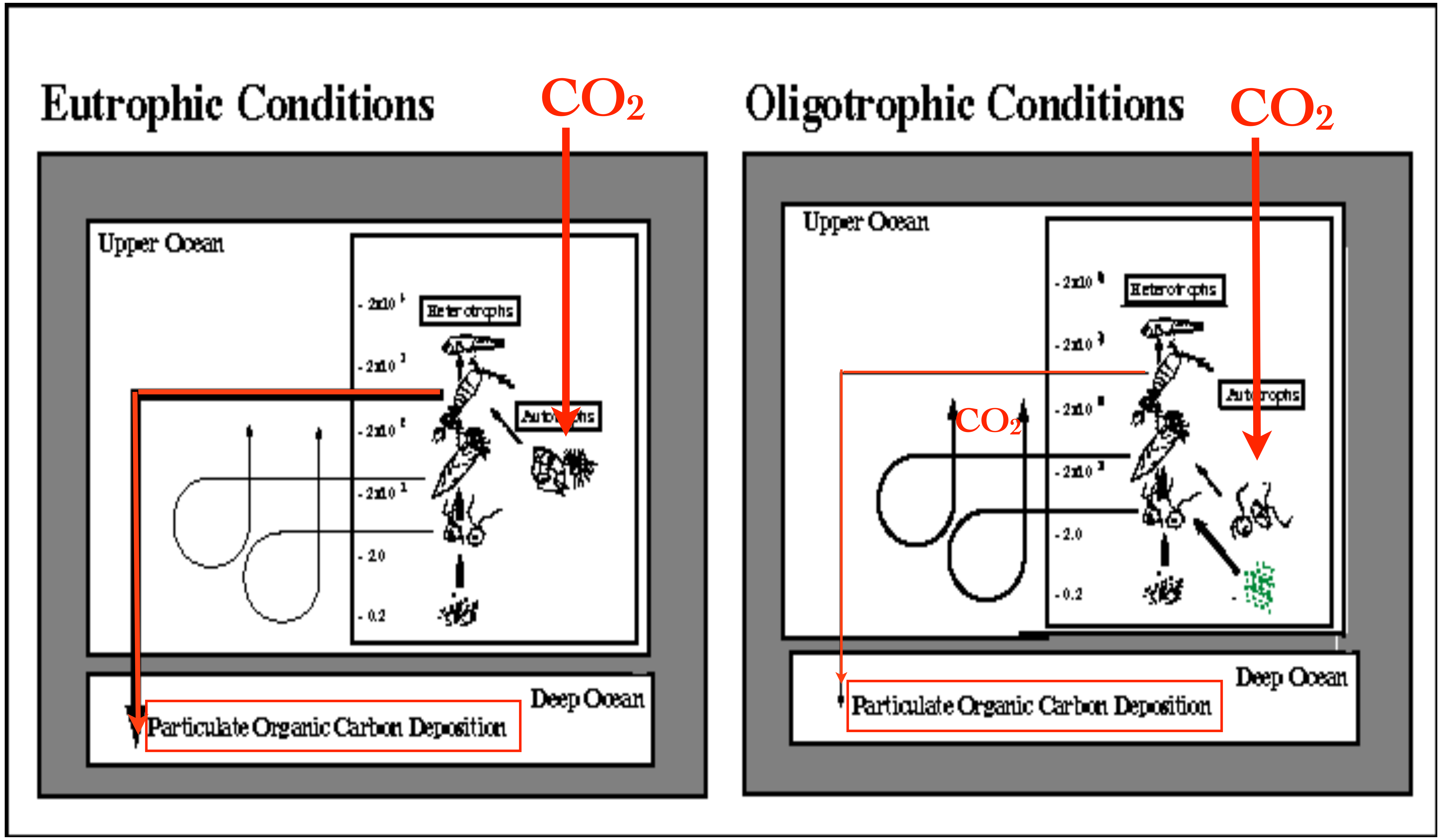
What would be desired is to know ***New*** Primary Production ==> ***Export*** Production.

Total Primary Production = ***Recycled*** + ***New*** Primary Production



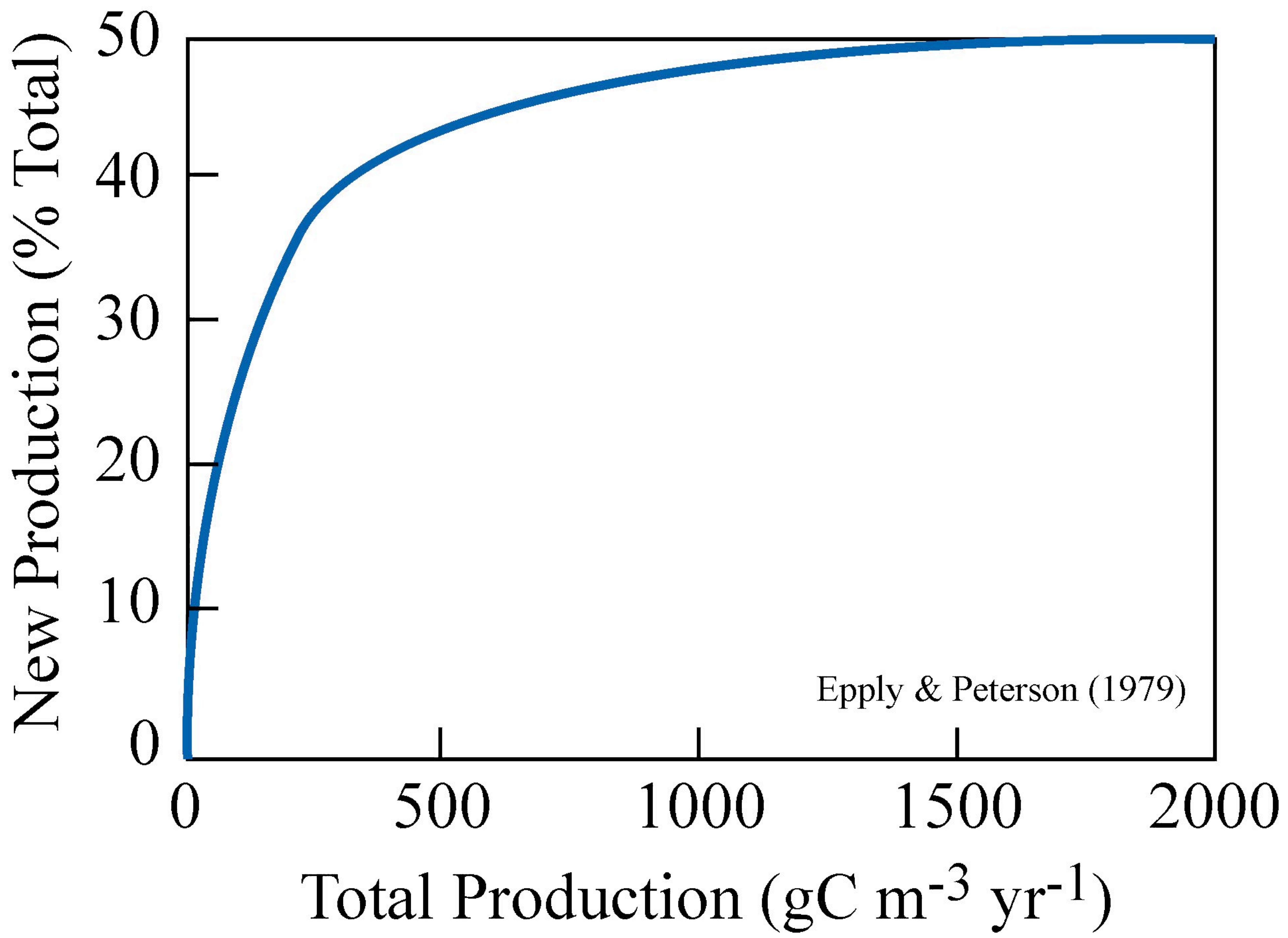
1. ***"Recycled"*** Primary production uses ***Ammonium (NH₄) generated by animal excretion*** in the upper ocean for its nitrogen source
2. ***"New"*** Primary Production uses ***Nitrate (NO₃) from the deep ocean*** for its nitrogen source.

Carbon Cycling and the Biological Carbon Pump



When the dominant phytoplankton cells are large, the dominant grazers are large and their large fecal material easily sinks to the deep ocean taking organic carbon down with it - this forms an ***efficient biological carbon pump***. The opposite is true when the dominant phytoplankton is small and grazers are small and fecal material is so small it cannot easily sink and the particulate carbon is instead respired back to CO_2 and overall the ***biological pump is inefficient***.

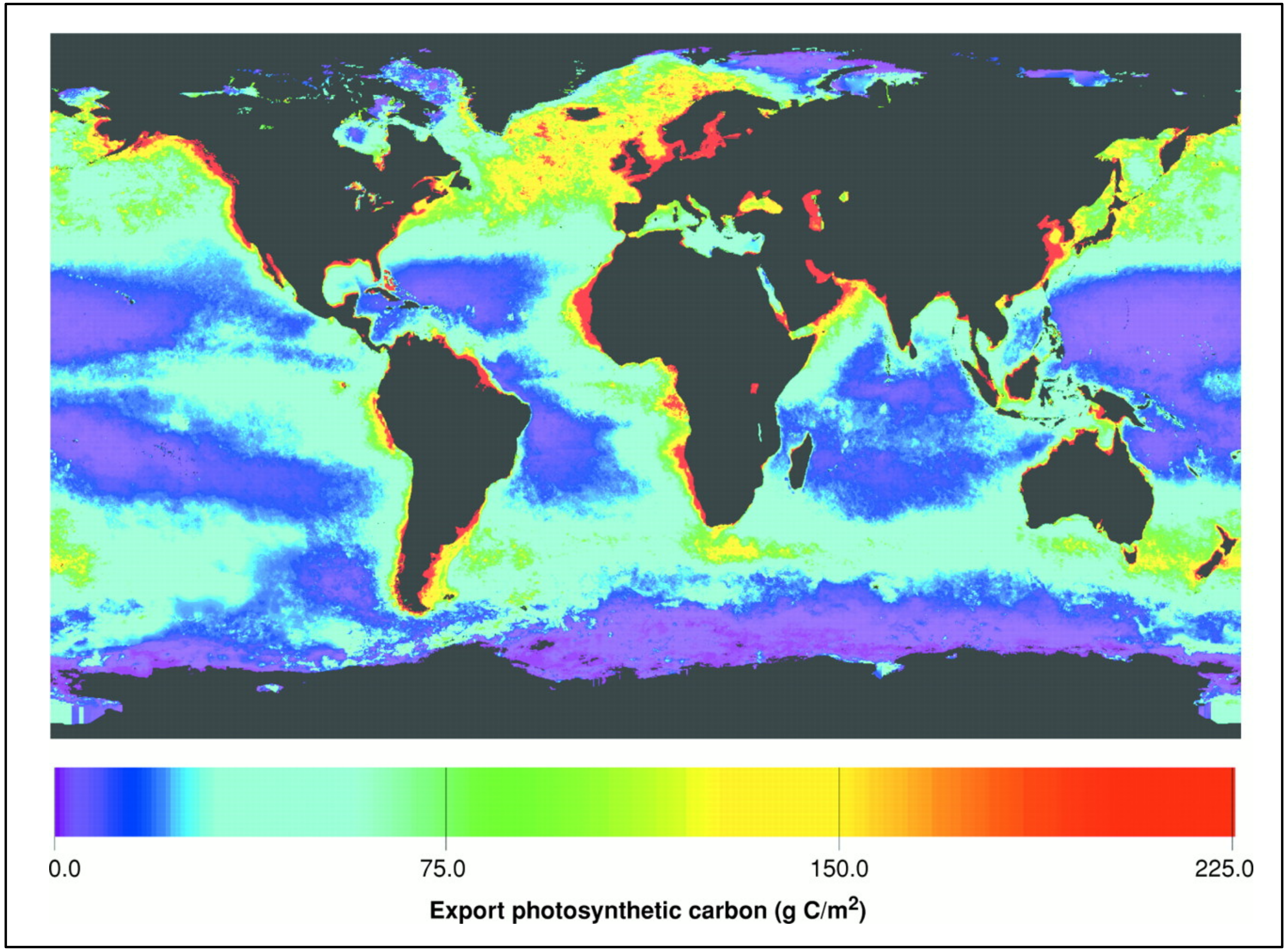
Empirical relationship between New and Total primary production known as the ***f-ratio***



A Rough Estimate of New/Export Production from Satellite-Derived Total Primary Production

Total Primary Production (NPP) at each pixel location is estimated using the VGPM model.

New/Export Production is estimated by simply multiplying Total production by the **f-ratio** at each pixel location.



Falkowski, Barber & Smetacek 1998 (Sci. 281:200-206)