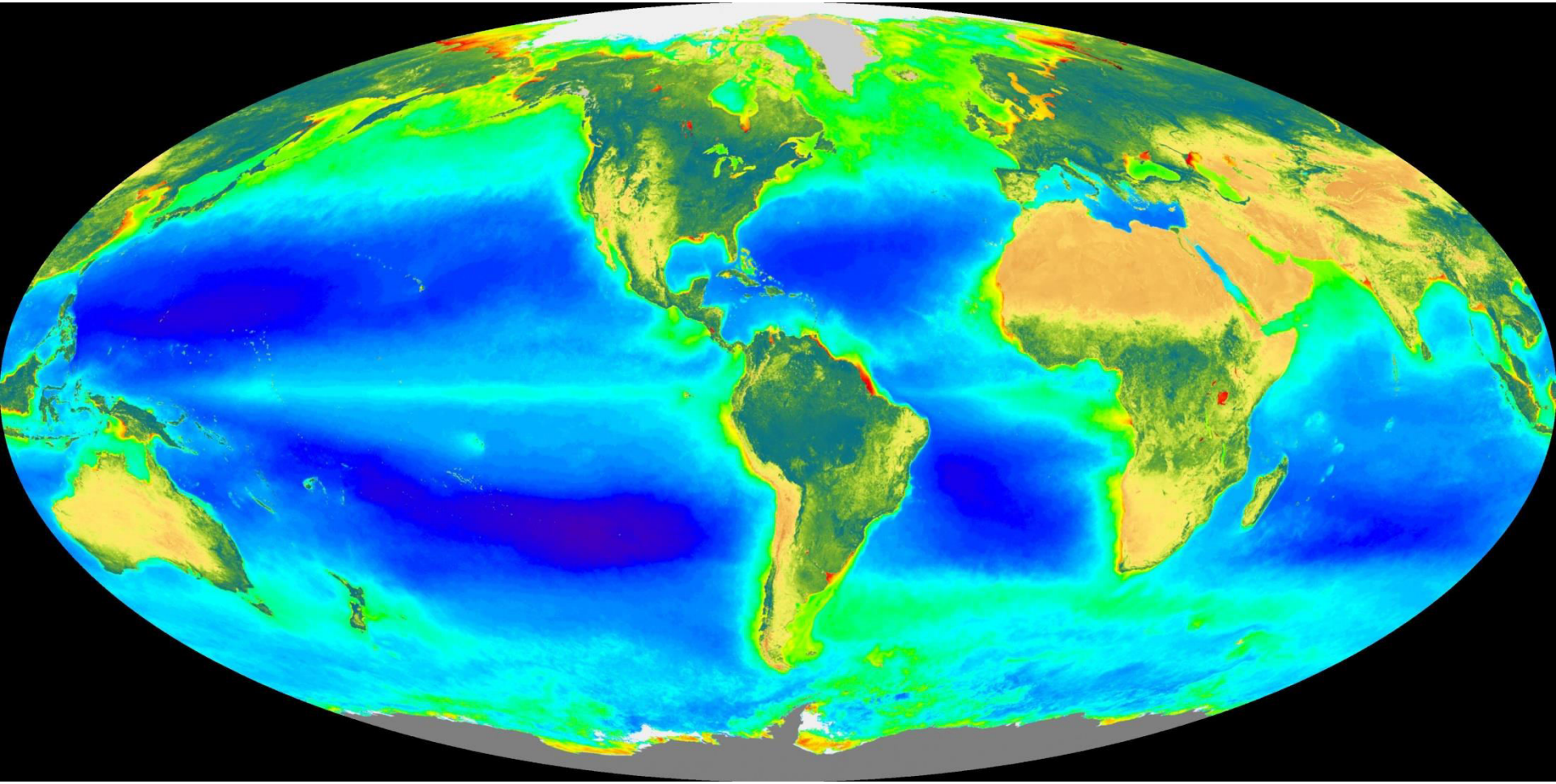
Fundamentals of Ocean Biogeochemistry

Nutrients, Productivity and nutrient cycle



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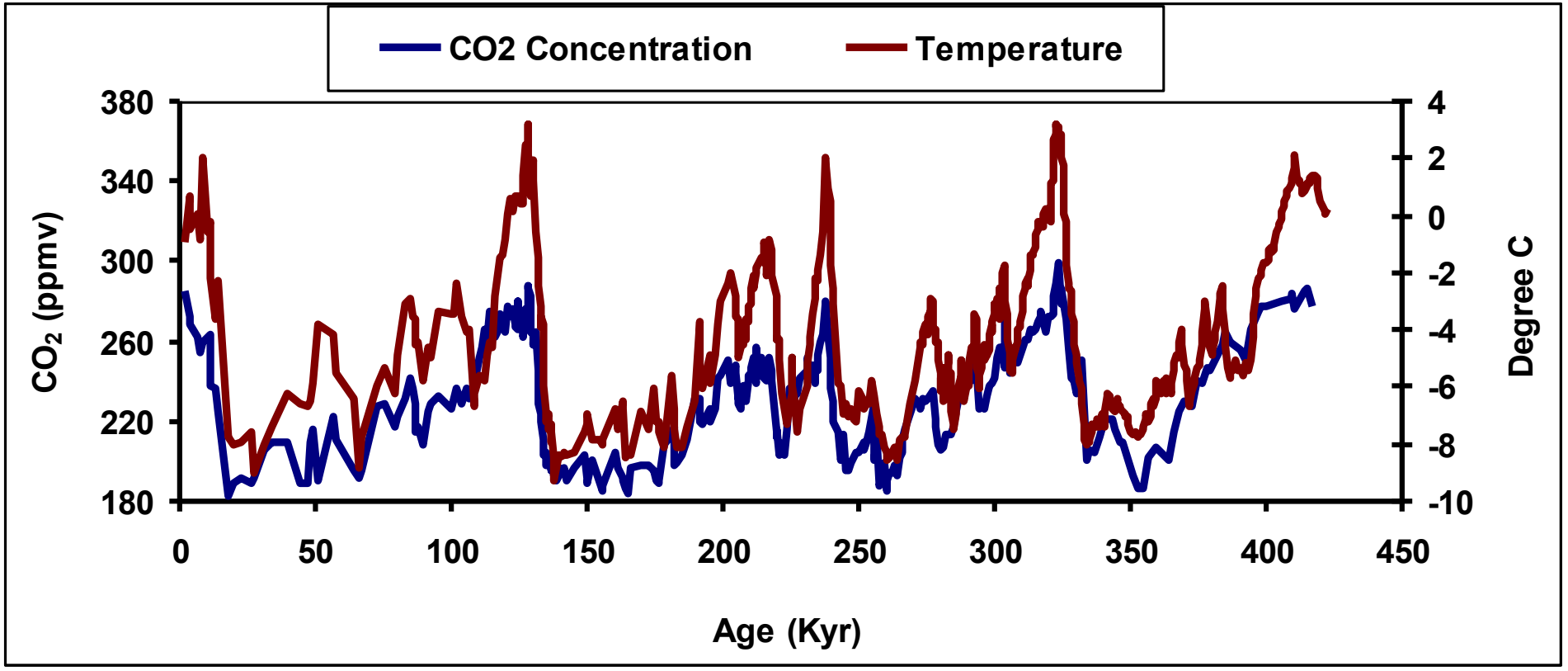
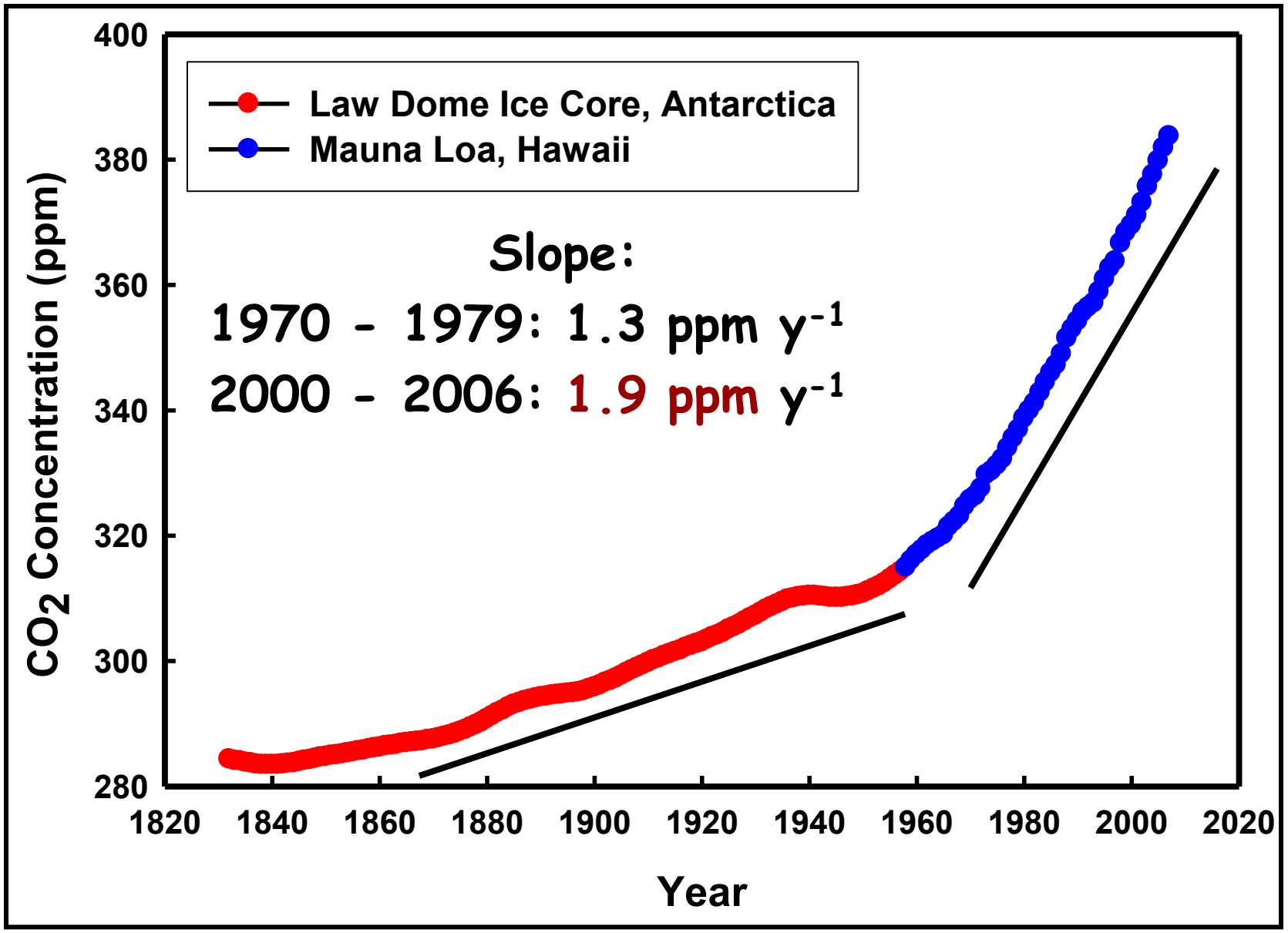
CO_2 – Temperature Relationship



VOSTOK Ice Core data


Law Dome Ice Core, Antarctica
Mauna Loa, Hawaii
Slope:
1970 - 1979: 1.3 ppm y-1
2000 - 2006: 1.9 ppm y-1
CO2 Concentration (ppm)
Year
400
380
360
340
320
300
280
1820
1840
1860
1880
1900
1920
1940
1960
1980
2000
2020

Partition of Anthropogenic Carbon Emissions into Sinks

45% of all CO_2 emissions accumulated in the atmosphere

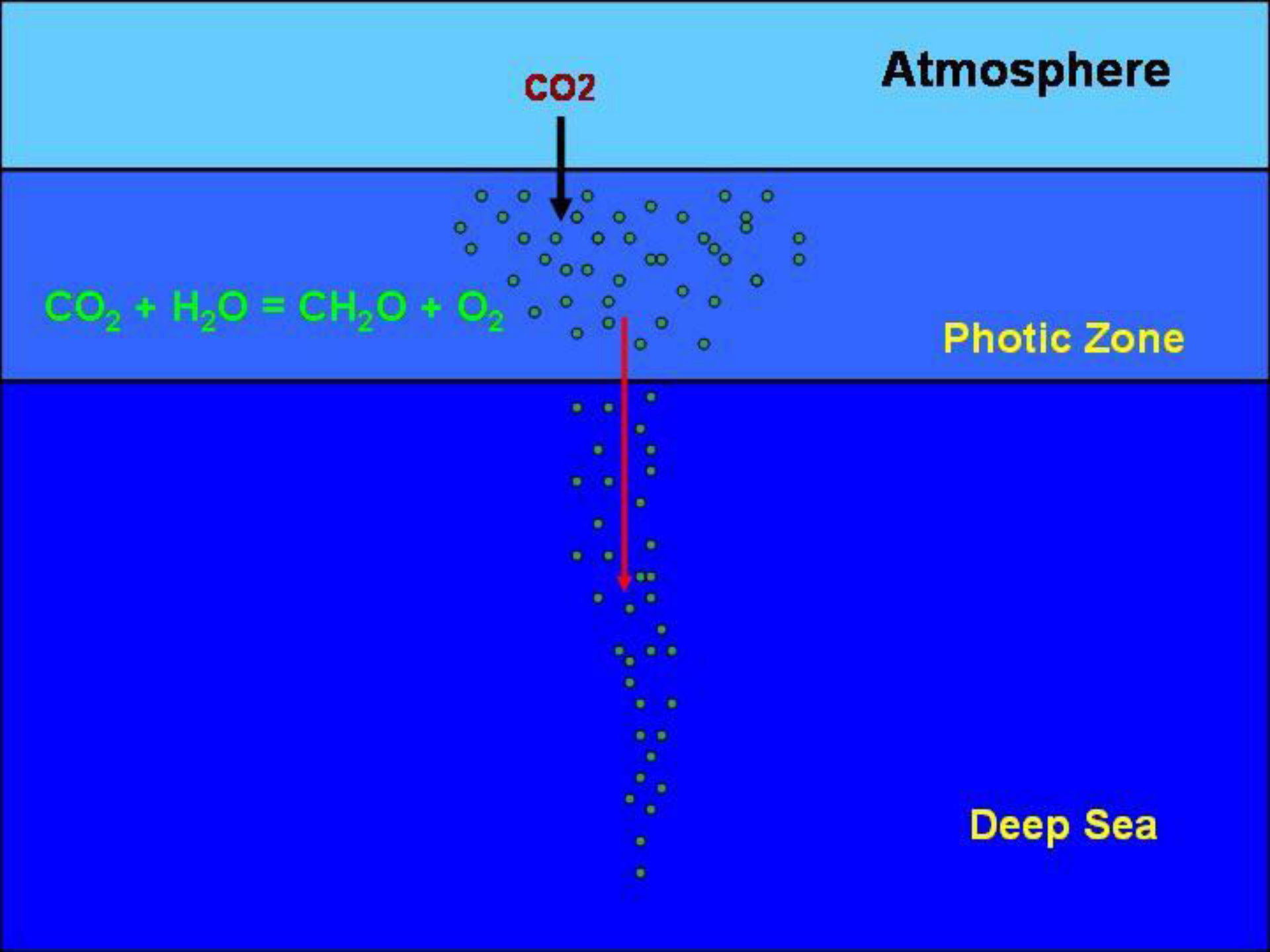
Oceanic Biomass: ~1Pg

Terrestrial Biomass: ~100 Pg

55% were removed by natural sinks

Ocean removes ~ 24%

Land removes ~ 30%


Atmosphere
CO2
$CO_2 + H_2O = CH_2O + O_2$
Photic Zone
Deep Sea

Depth of photic zone

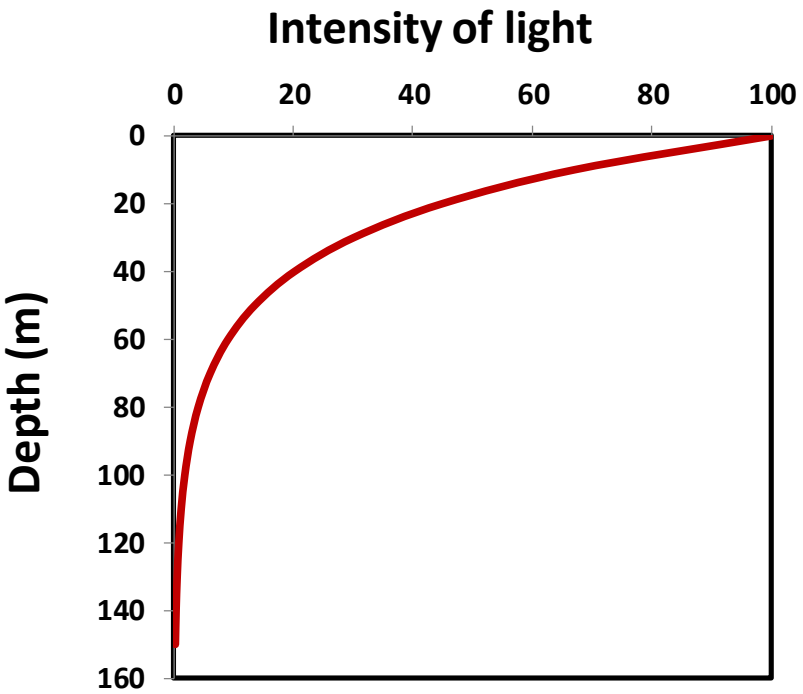
Light penetration in the ocean is describes by a simple exponential decay law

$$I(z)=I(o)\ e^{-(Kz)}$$

Where K is diffused vertical attenuation co-efficient, with dimension (L^{-1})

A vertical distance K^{-1} is said to be one optical depth

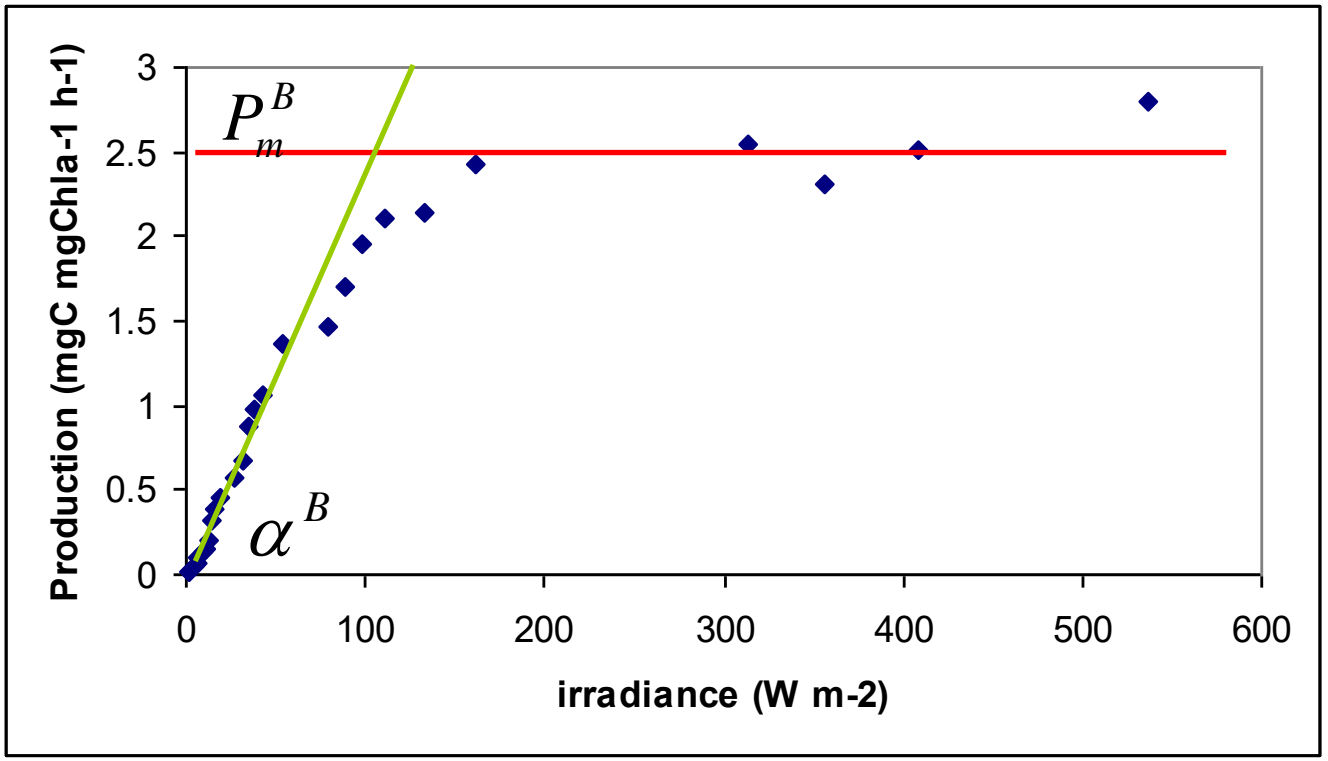
For example, Zp, the photic depth (surface to 1% light level) extends for 4.6 optical depths:



$$z_p = \frac{1}{K}\log_e\left(\frac{I(0)}{I(z)}\right) = \frac{1}{K}\log_e 100 \approx \frac{4.6}{K}$$

Production-light relationship

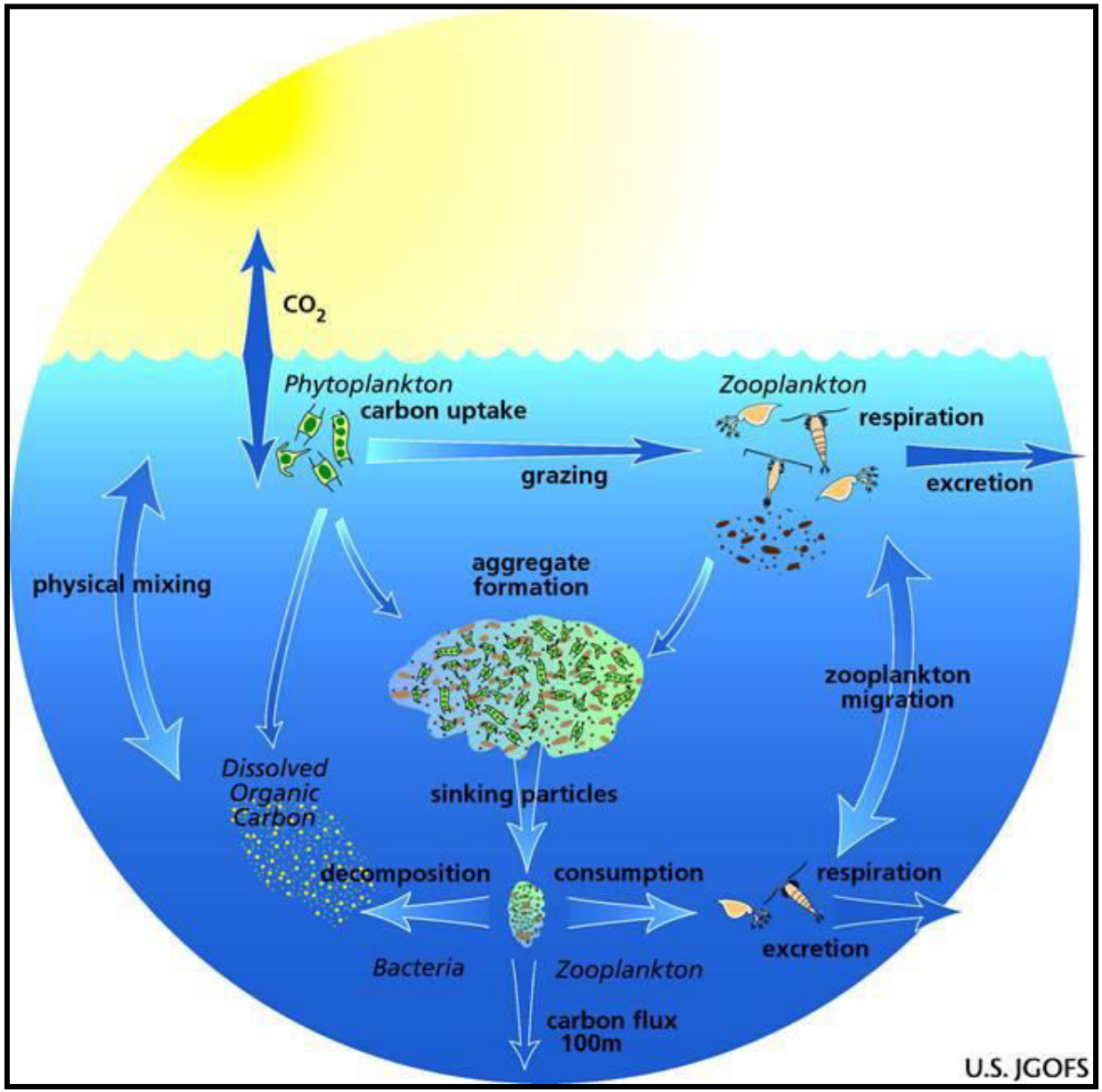
- Rate of photosynthesis = production
- Production varies mainly in function of light and biomass
- Functional response of phytoplankton photosynthesis to available light studied from photosynthesis-light experiment (P-I curve)



Primary Productivity

- Gross Primary Productivity (GPP) – the rate at which an ecosystem's producers capture and store a given amount of chemical energy as biomass in a given period of time.
- Net Primary Productivity (NPP) – the rate at which all the plants in an ecosystem produce net useful energy; equal to the difference between energy produced through photosynthesis and energy used for cellular respiration.

The Biological Pump



- Plankton grow, mature and die—taking carbon with them to the deep ocean

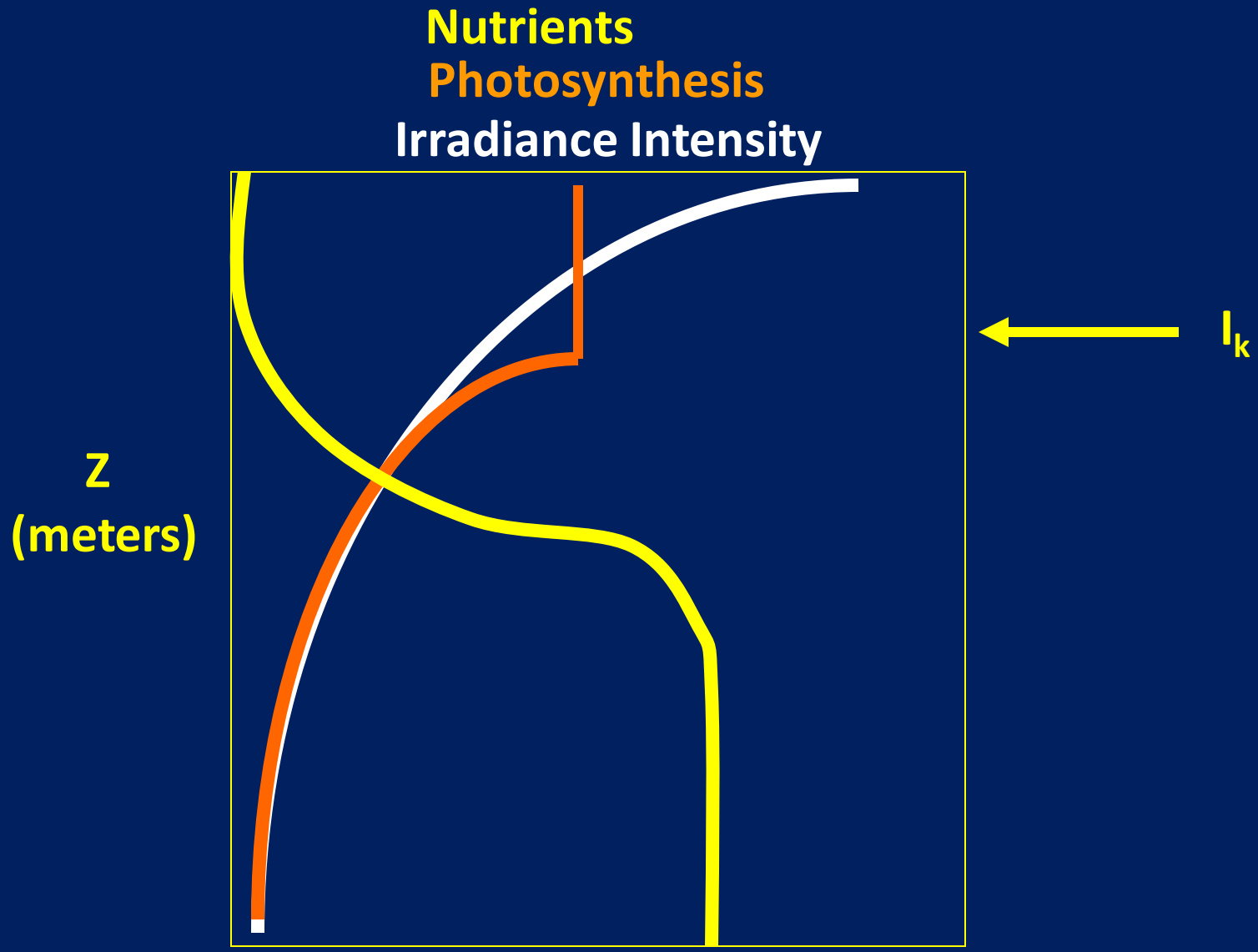
- They have a larger effect on climate than any single other process or group of organisms

- 99% of marine life relies on plankton—they form the base of the marine food chain.

- About 10% of the carbon fixed by photosynthesis in the surface layer, escapes this layer by sinking into the deep ocean. This flux is called *New Production* or *Export Production*.

The Ocean

Euphotic zone	light - ~little N
Aphotic zone	no light - lots N


Nutrients
Photosynthesis
Irradiance Intensity
Z
(meters)
I_k

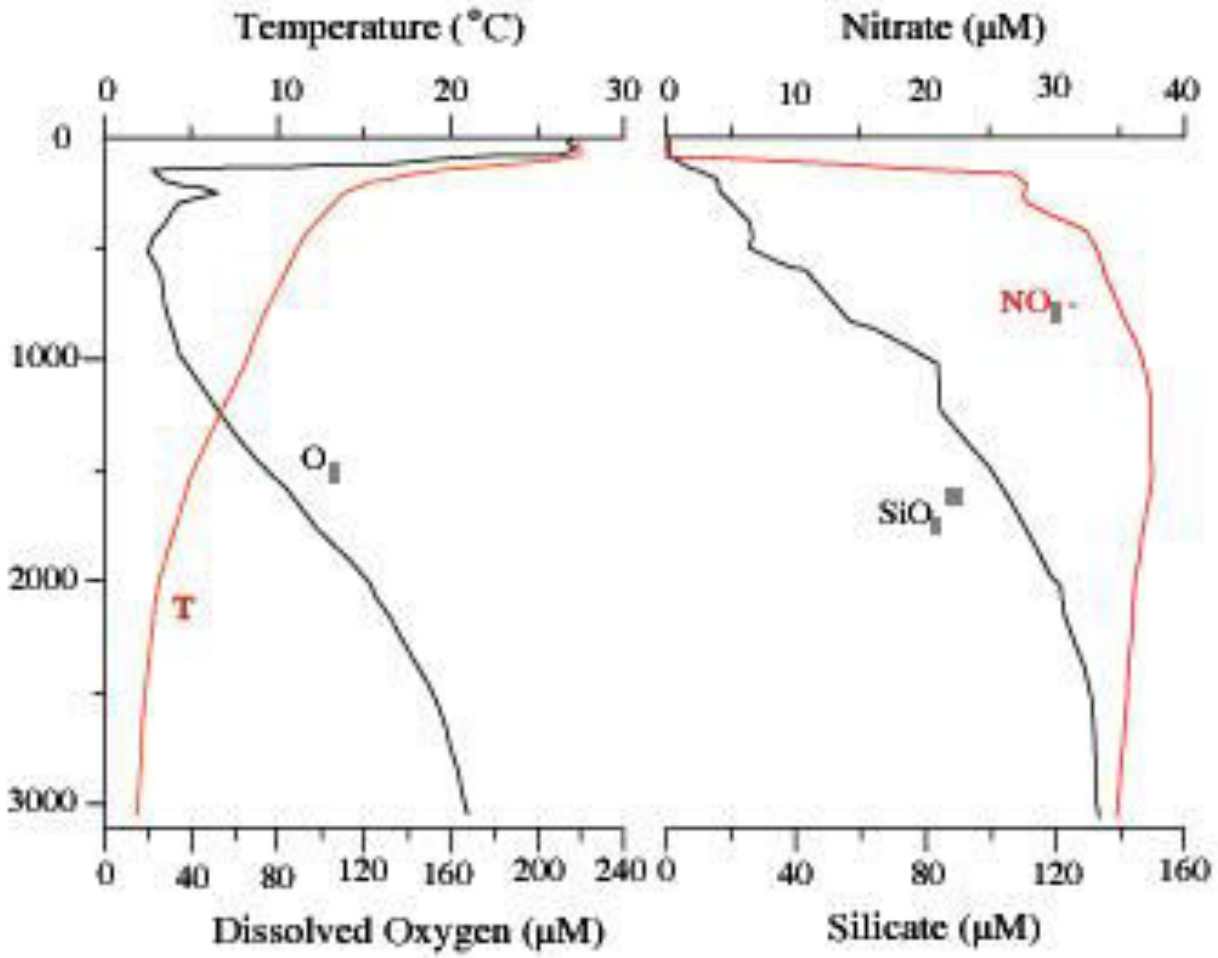
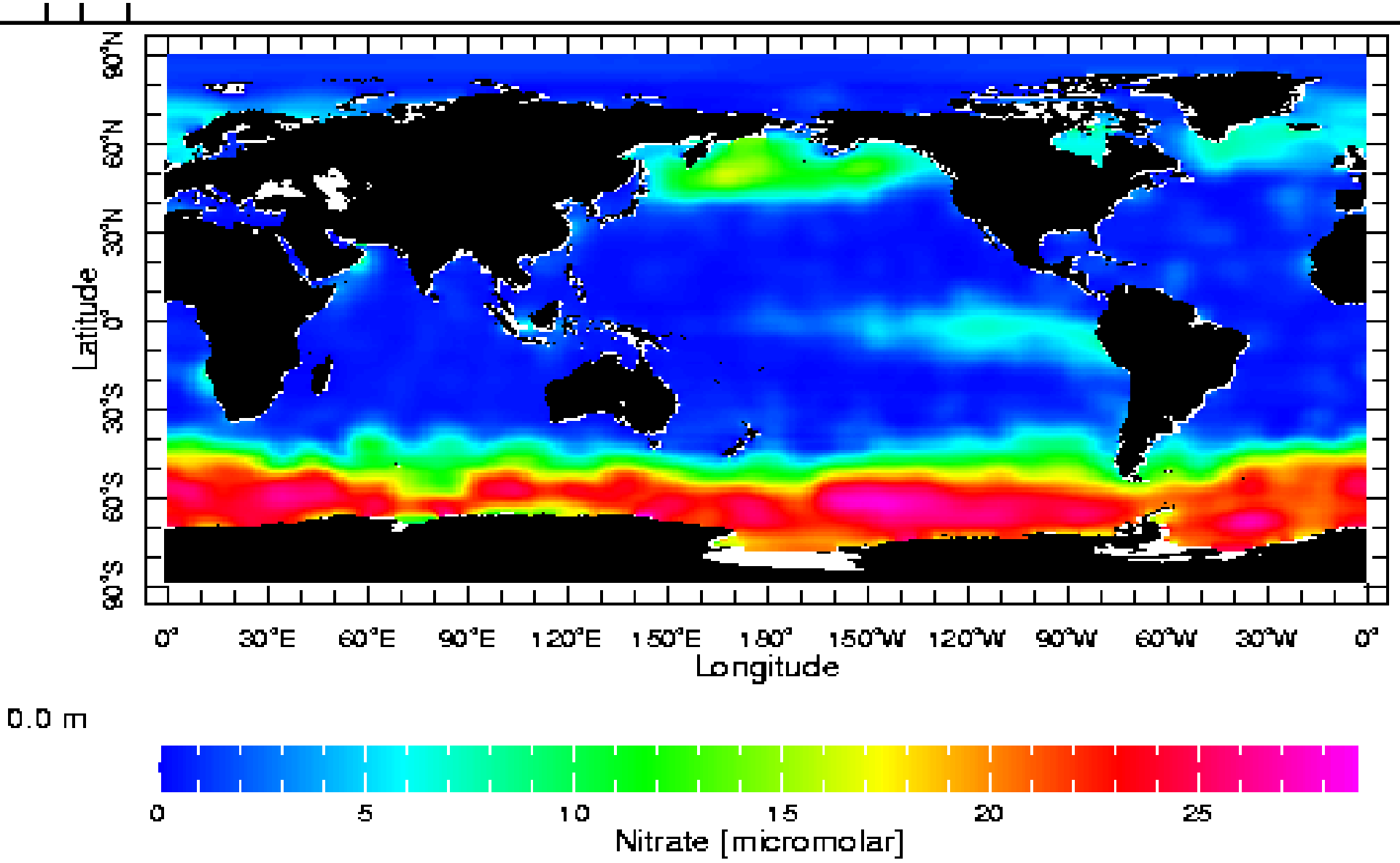


Figure 3. Typical vertical distributions (profiles) of temperature, dissolved oxygen, nitrate and silicate in the water column at 10°N and 67°E in the Arabian Sea. The thin water layer, at the top of the ocean, with near uniform levels in properties represents the surface mixed layer.

Nitrate distribution in world ocean



Major Nutrients

phytoplankton need: light CO_2 nutrients water

- Nitrogen (NO_3^-, NO_4^{2-}, & NH_4^+)
  - –Limiting in marine systems
- Phosphorus (PO_4^{3-})
  - –Limiting in freshwater systems
- Silica (SiO_2)
  - –Important to diatoms
- Redfield ratio

  106 : 15 : 16 : 1

  C Si N P

In the ocean, light and nutrient availability may limit the rate of photosynthesis.

Redfield-Ketchum-Richards Equation

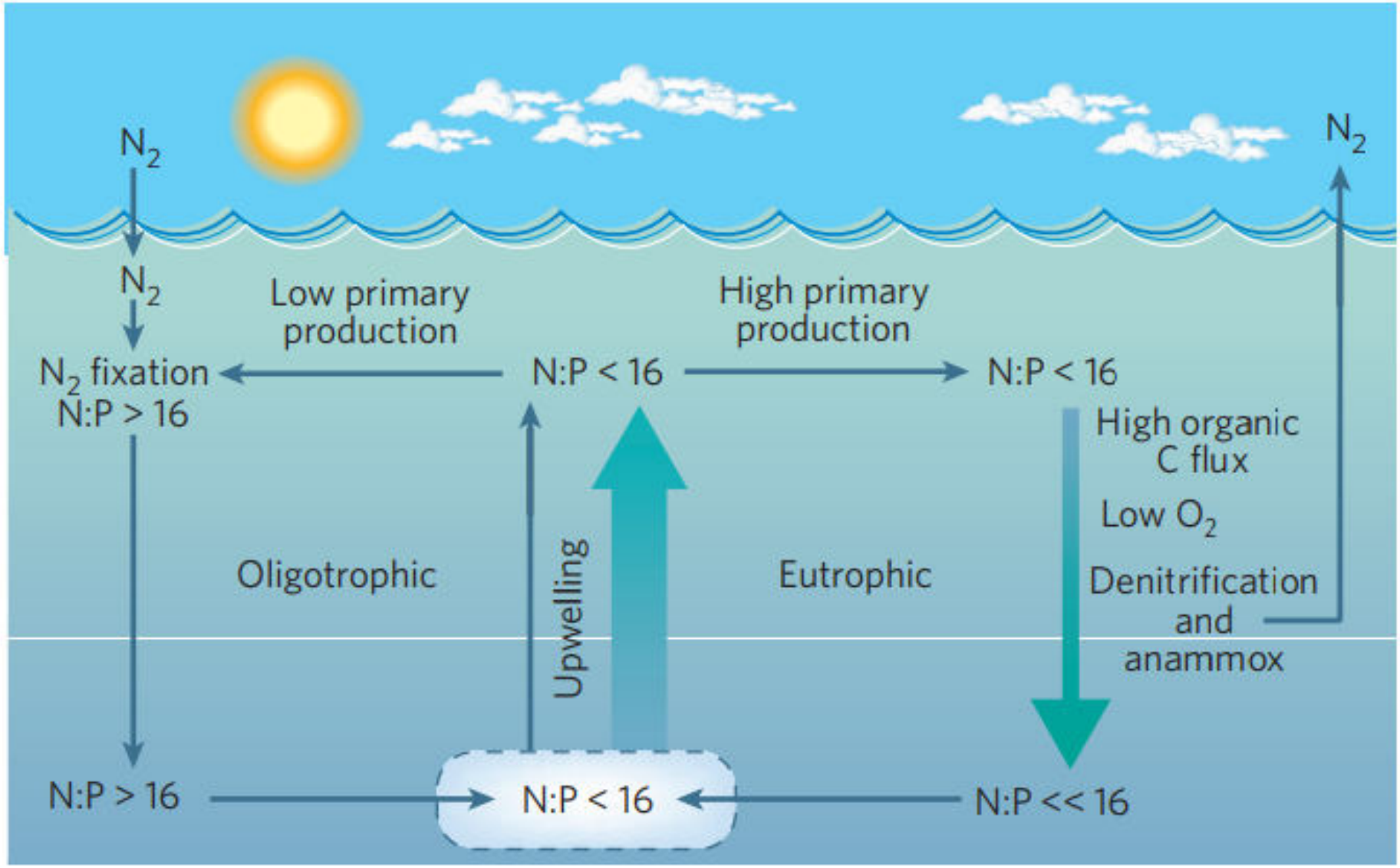
The data for the elemental composition of the plankton were assembled to construct an equation to represent average photosynthesis and respiration.

The elemental ratio of plankton is called **Redfield Ratio**

C:N:P :: 106:16:1

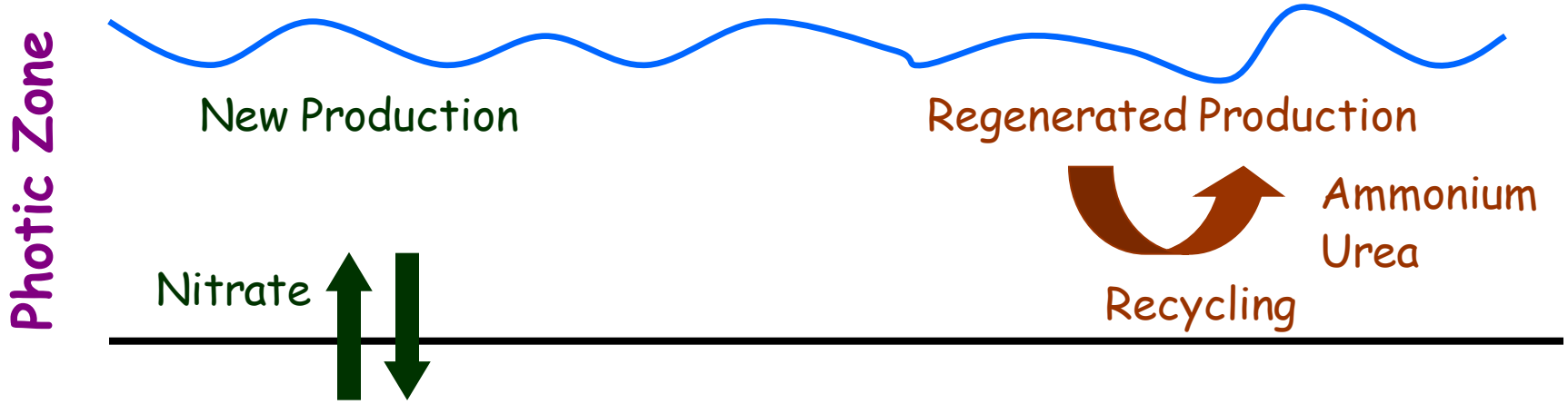
RKR equation for average photosynthesis and respiration is

$$106CO_2 + 16HNO_3 + H_3PO_4 + 122H_2O + \text{Trace elements} = C_{106}H_{263}O_{110}N_{16}P + 138O_2$$


N_2
N_2
N_2
Low primary production
High primary production
N_2 fixation
N:P > 16
N:P < 16
N:P < 16
High organic C flux
Low O_2
Oligotrophic
Upwelling
Eutrophic
Denitrification and anammox
N:P > 16
N:P < 16
N:P << 16

Components of primary production

Total Production = New production + Regenerated production



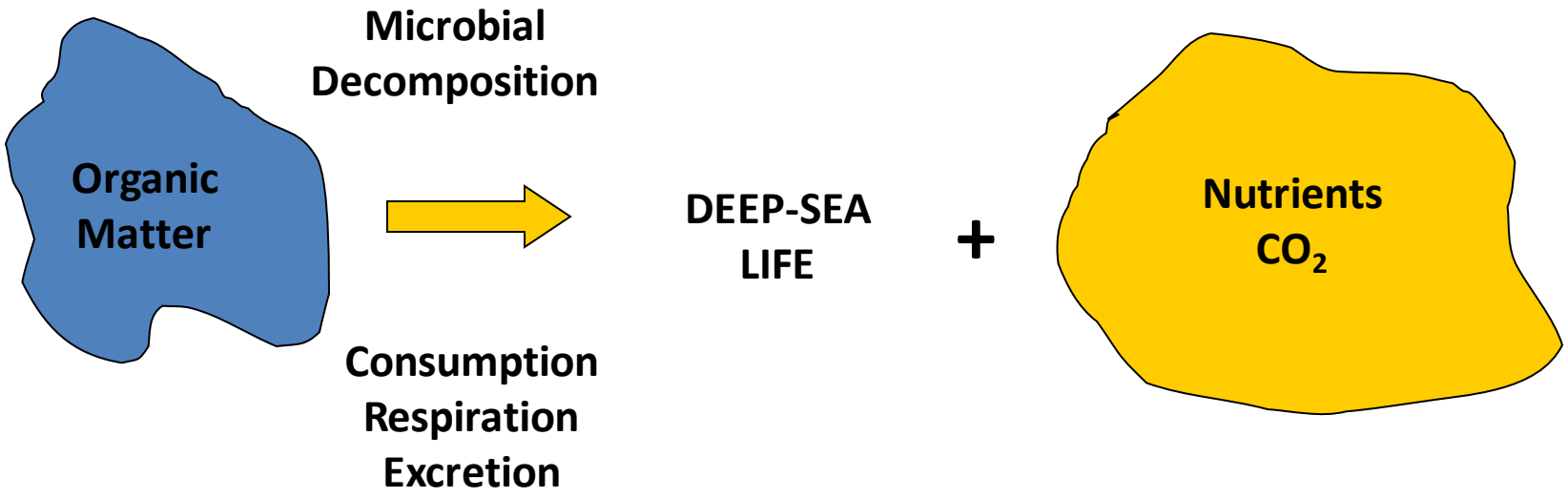
New Production is defined as production due to newly borne nitrate into surface layer

Regenerated Production is uptake of recycled nutrients such as ammonium and urea

f-ratio = New Production / Total Production

New Production ≡ Export production

Consumption and Decomposition
(deep ocean)



Result:

- ***Less suspended particulate organic matter***
- ***More dissolved inorganic nutrients (N, P, Si)***
- ***Supersaturated dissolved inorganic carbon (CO_2)***

Sources and sinks of dissolved Oxygen

Sources:

Physical exchange between atmosphere and Ocean, mainly diffusion

By product of photosynthesis

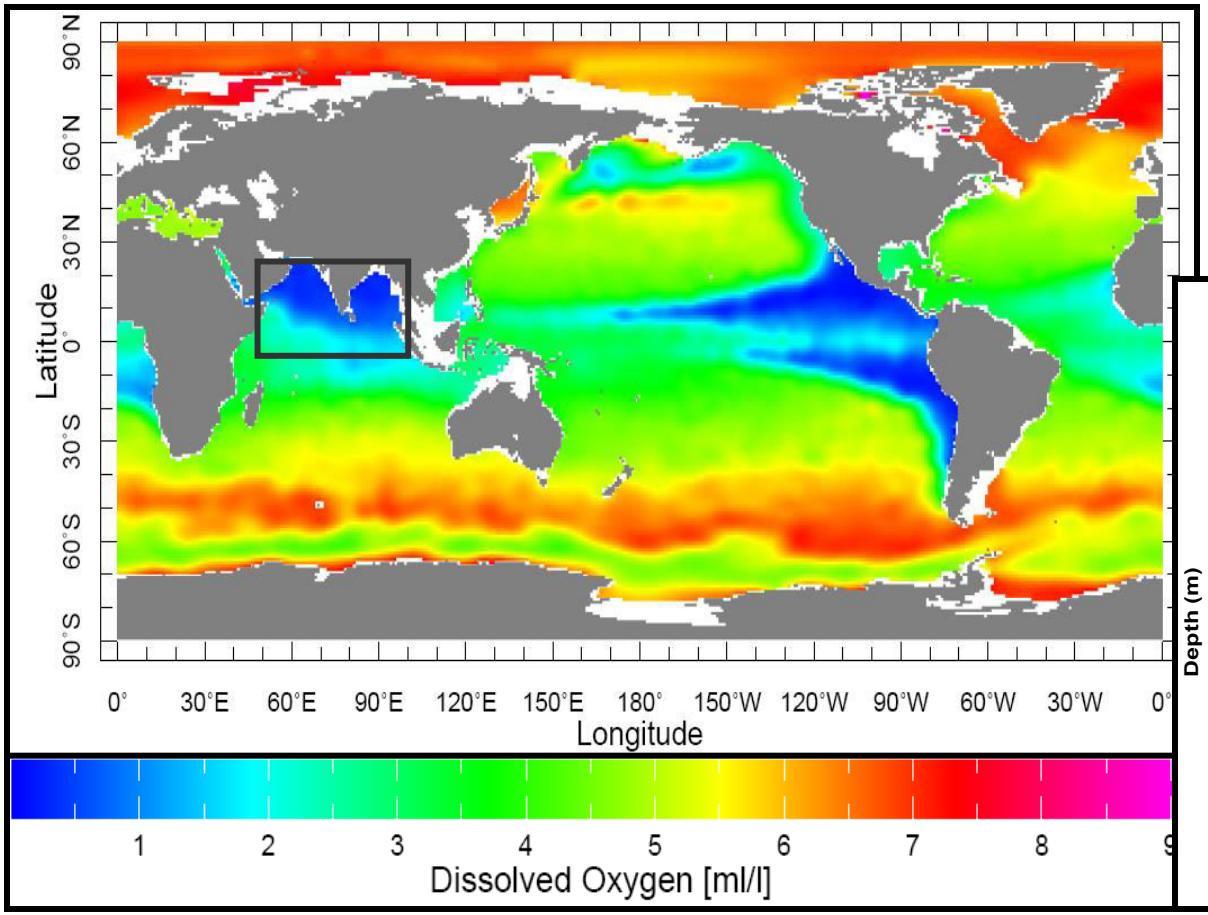
Sinks:

Community respiration

Bacterial degradation of organic matter

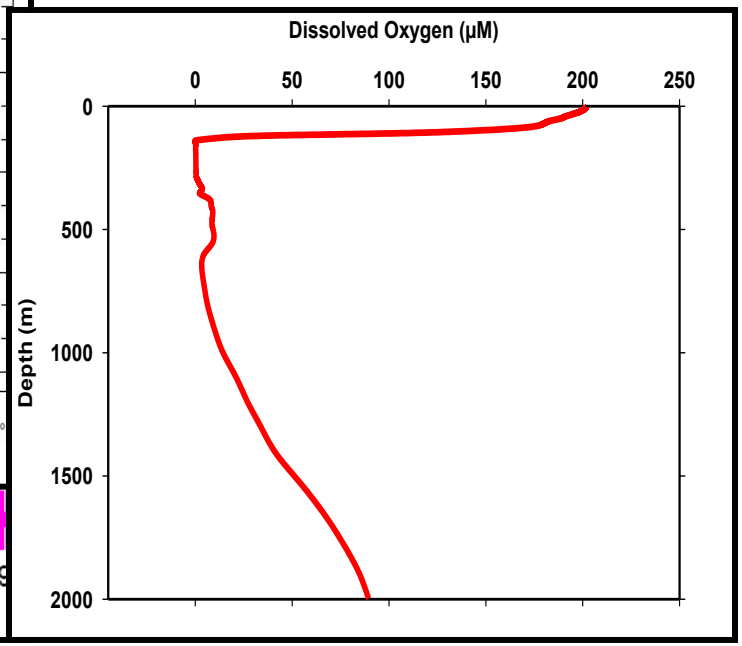
Leads to formation of oxygen depleted zone in the sub-surface layer (100 – 1000m)

Dissolved Oxygen in Sub-surface water



Oxygen profile in the Central Arabian Sea

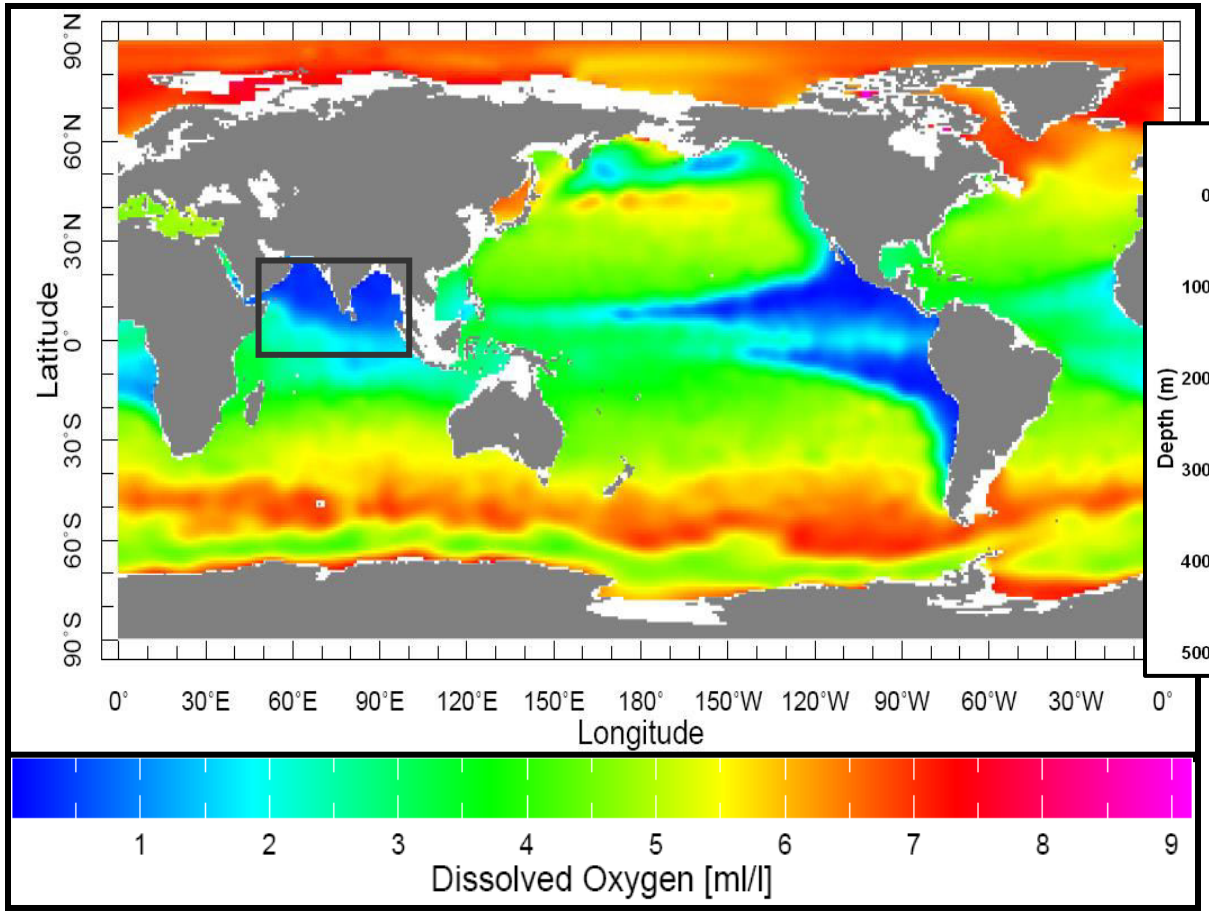
11.9°N 65.3ºE



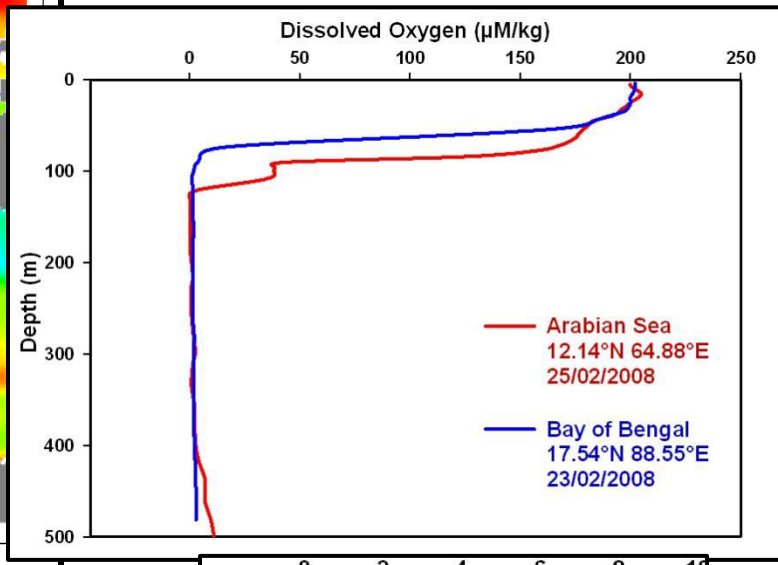
Major Oxygen minimum zones around the world's Ocean: Arabian Sea, Eastern Tropical North Pacific (ETNP) and Eastern Tropical South Pacific (ETSP) A map showing the annual mean dissolved oxygen levels at 200 m below surface .

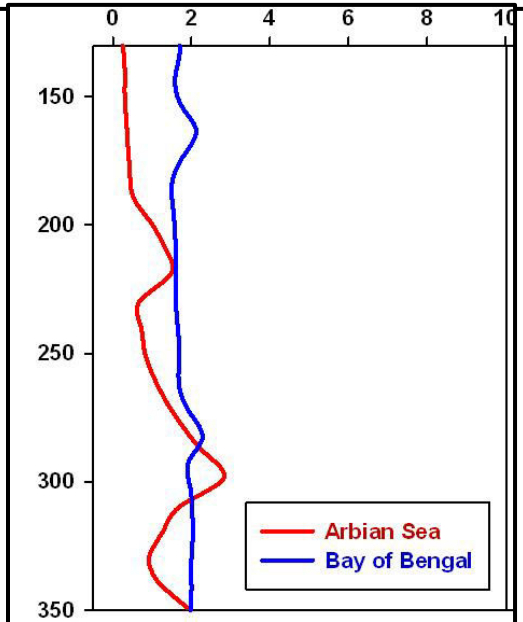
Source: Levitus Climatology

Dissolved Oxygen in Sub-surface water



Oxygen profiles in the Northern Indian Ocean





Major Oxygen minimum zones around the world's Ocean. A map showing the annual mean dissolved oxygen levels at a depth of 200 m. Source: Levitus Climatology

- In the Indian Ocean, OMZs are found in both the Arabian Sea (AS) and the Bay of Bengal (BoB)
- The Arabian Sea OMZ (ASOMZ) is the second most-intense OMZ of the world ocean and is usually observed between 100-m and 1000-m depths, with oxygen concentrations less than or equal to 20 µmol/L
- The oxygen concentrations in BOBOMZ are more or less constant

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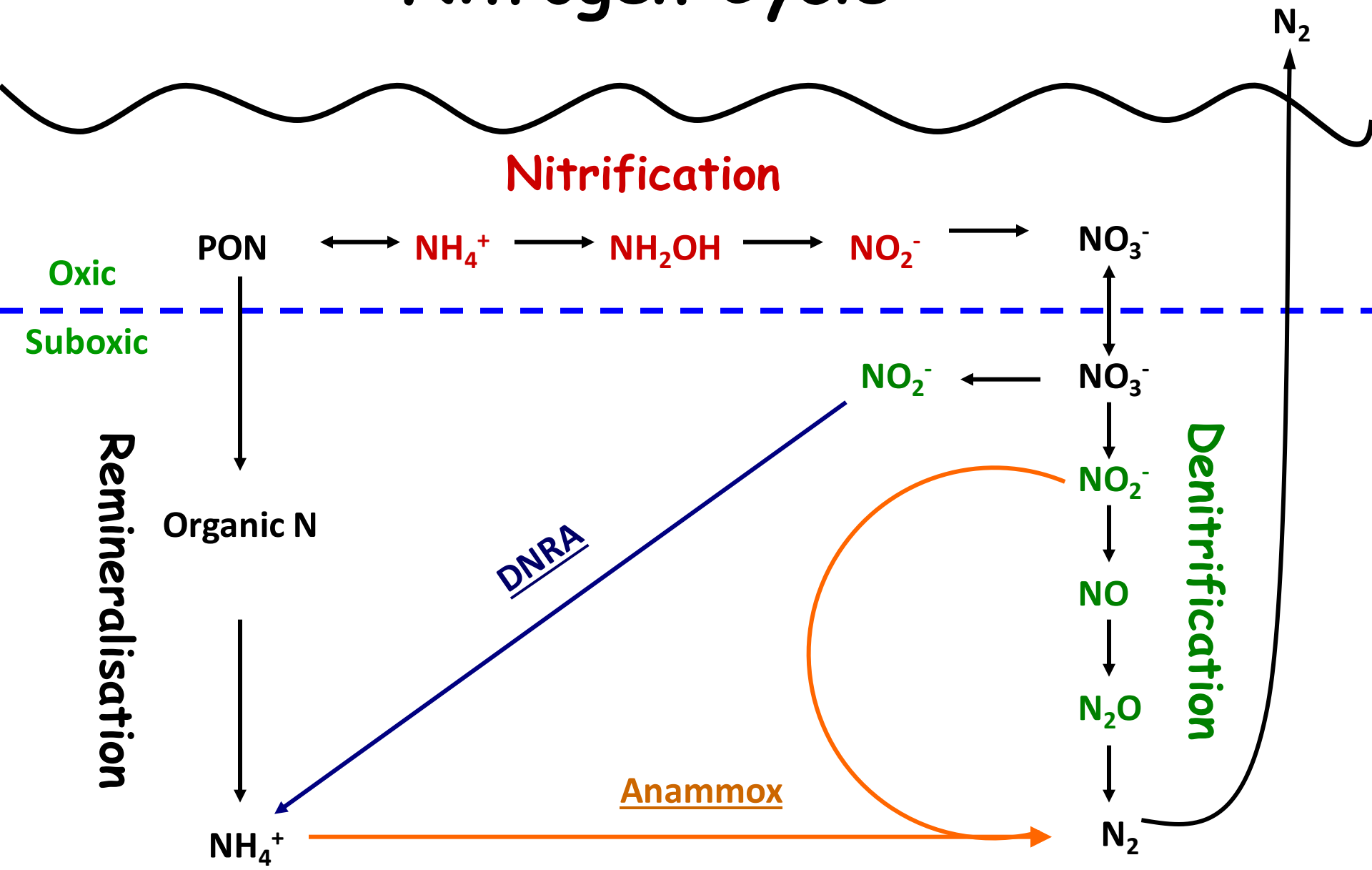
Oxic Zone : Region in where dissolved oxygen is abundant (O2 more than 100 µmol/kg)

Hypoxic zone : A typical threshold for hypoxic zone is approximately 60 µmol/kg (~10-60µm/kg)

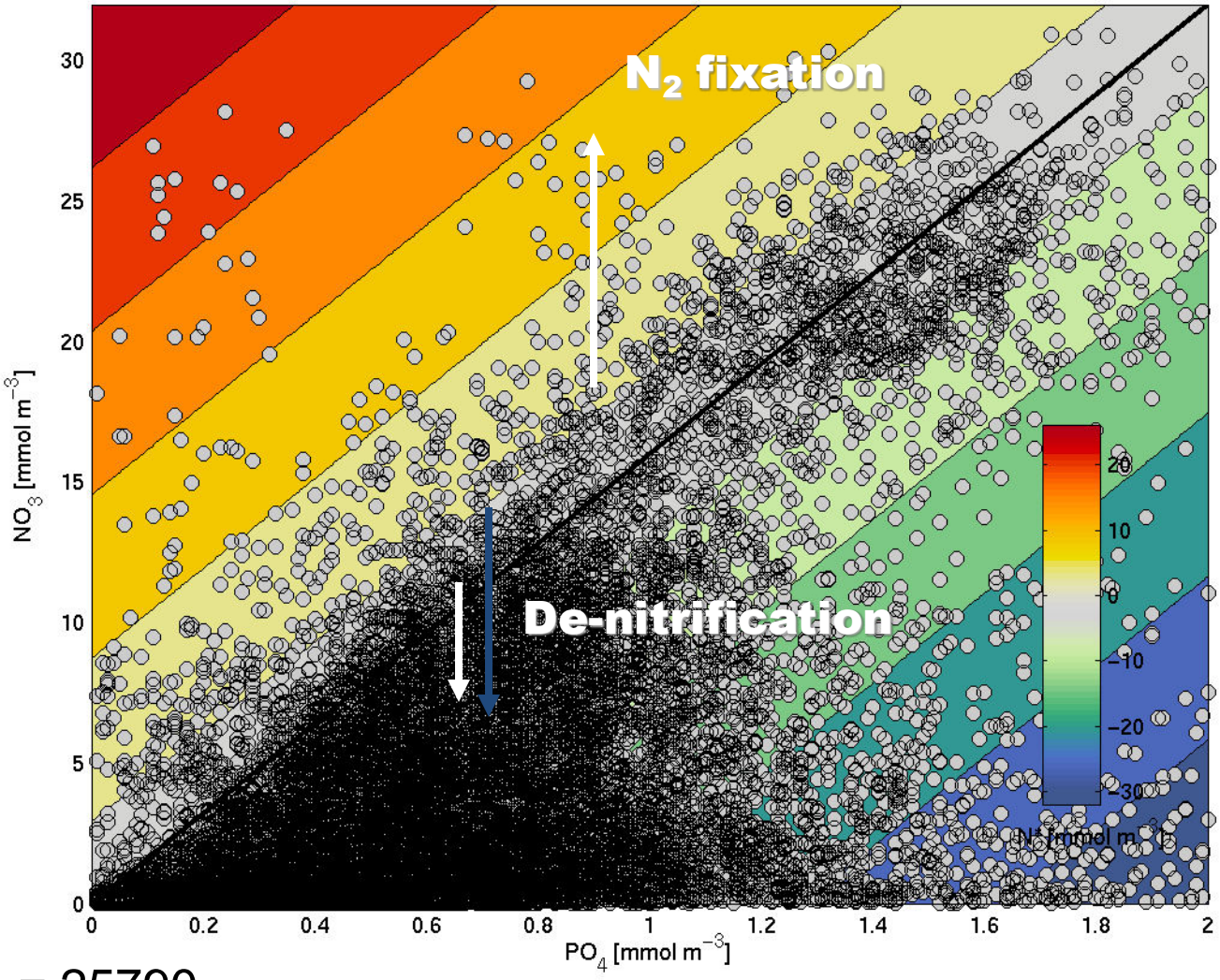
Suboxic zone : The suboxic zone is defined as a region which experience nitrate reduction but not sulphate reduction (Suboxic range : O2 < 2-10 µmol/kg)

Anoxic zone : region which experience complete depletion of oxygen and are a more severe condition of suboxia (~0µm/kg)

Nitrogen Cycle



What alters Redfield Ratio?



N = 25790

$$N^* = N - 16\,P$$

Deoxygenation in the Indian Ocean: Implications to fisheries

Printed from
THE TIMES OF INDIA

Fish catch across India drops by 5%

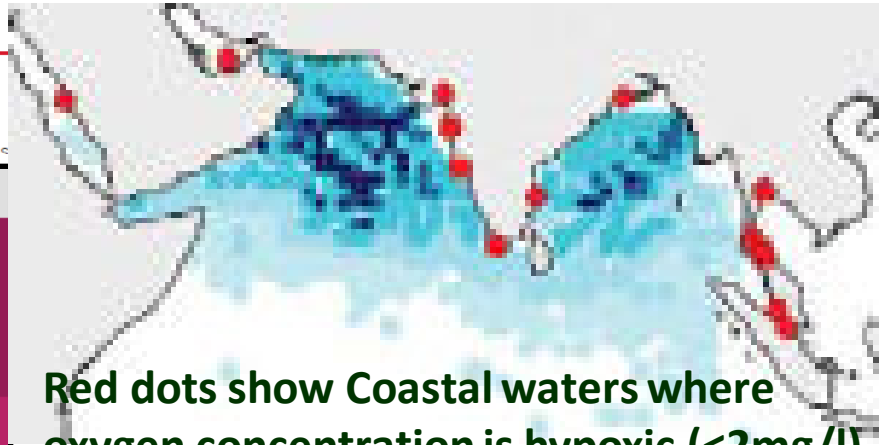
TNN | May 3, 2015, 03.26 AM IST

OCHI: Fish lovers across India should brace themselves

climate change wildlife energy pollution

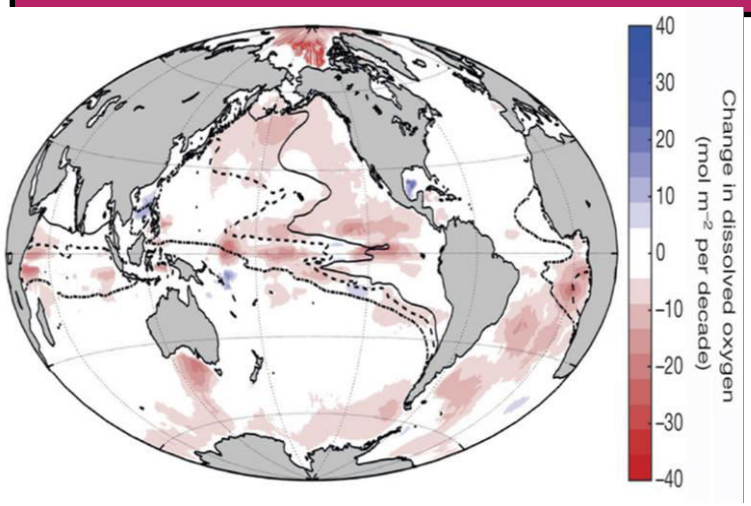
Bay of Bengal: depleted fish stocks and huge dead zone signal tipping point

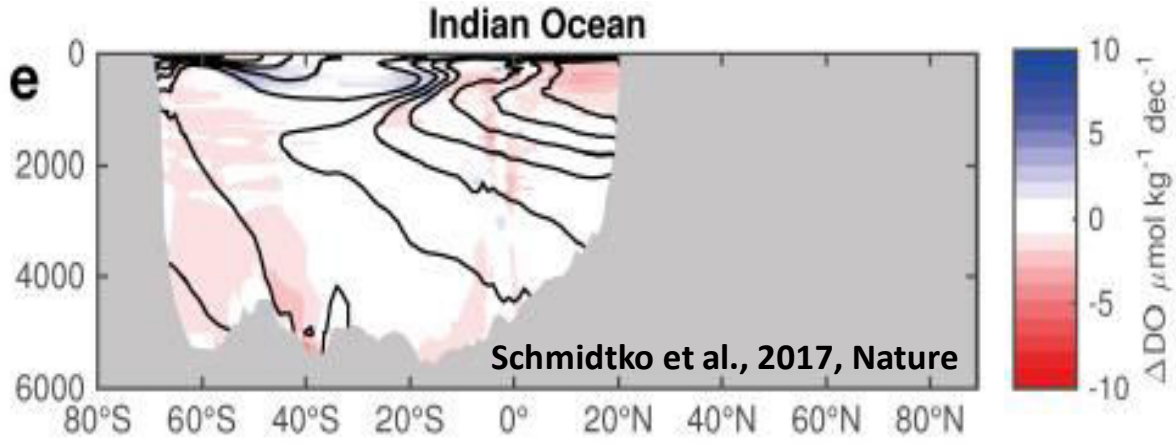
Long treated as a bottomless resource pit, over-exploitation of the ocean, pollution and rising sea levels are having a catastrophic impact on life in the bay



Red dots show Coastal waters where oxygen concentration is hypoxic (<2mg/l)

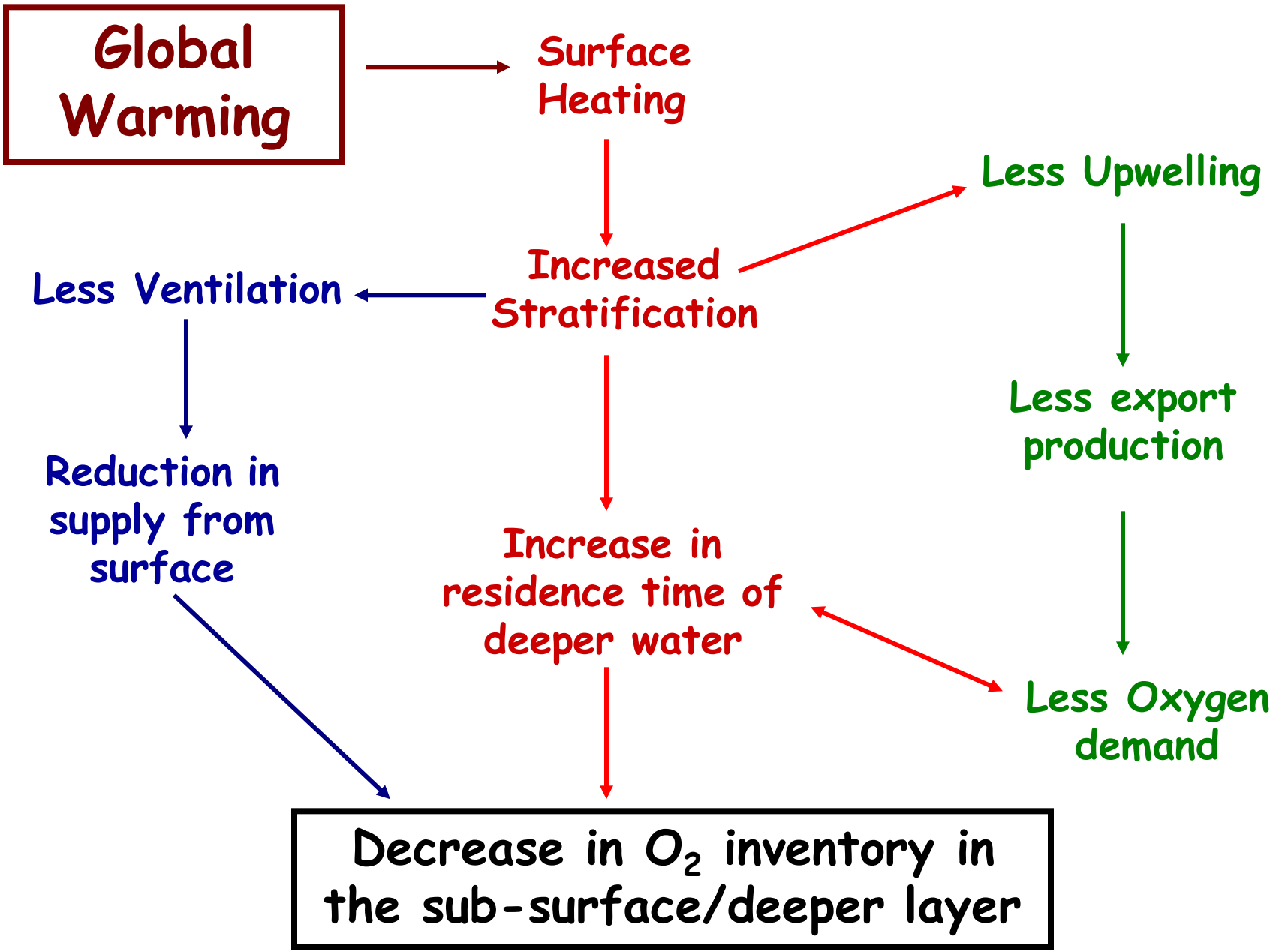
Breitburg et al., 2018, Science





- **Oceanic oxygen levels had fallen by 2% in 50 years.**
- **Amount of oxygen lost could reach up to 7% by 2100**
- **More than 500 new hypoxic sites**
- **Depletion of oxygen threatens future fish stocks and risks altering the habitat and behaviour of marine life**

Climate Change and Dissolved Oxygen



Thank you