## LECTURE 1:

**PRIMARY PRODUCTION (PP) AND RELATED PROCESSES**

**AIM: TO ACT AS A BASIS FOR LECTURES 2 & 3**

- **BASIC DEFINITIONS**
- **TYPICAL RANGES AND UNITS**
- **MEASUREMENT OF PROCESSES**
- **TREATMENT OF DATA FOR INPUT TO PP MODELS**

## LECTURE 2:

**MODELLING PP AT LOCAL SCALES**

## LECTURE 3:

**MODELLING PP AT OCEAN-BASIN SCALES**

## LECTURE 2:

**MODELLING PRIMARY PRODUCTION ON LOCAL SCALES**

**AIM:**

**TO DESCRIBE A PARTICULAR METHOD FOR COMPUTING PP ON A LOCAL SCALE**

KEY REFERENCES:

- PLATT & SATHYENDRANATH (1988)- *Science, 241, 1613-1620;*
- SATHYENDRANATH *et al.* (1989) - *DSR 36, 431-453*

## LECTURE 3:

**MODELLING PRIMARY PRODUCTION ON OCEAN-BASIN SCALES**

**AIM:**

**TO DESCRIBE EXTRAPOLATION OF THE LOCAL MODEL TO LARGE HORIZONTAL SCALES**

KEY REFERENCES:

- PLATT & SATHYENDRANATH (1988)- *Science, 241, 1613-1620*
- LONGHURST *et al.* (1995) - *J Plankton Res* 17(6) 1245-1271;
- SATHYENDRANATH *et al* (1995) *DSRI* 42(10): 1773-802;
- WATTS *et al* (1999) *MEPS* 183: 1-12

## SOME BASIC PROPERTIES OF OCEANIC PHYTOPLANKTON

- **MICROSCOPIC ORGANISMS: (<1µm TO 100 µm)**
- **PLANTS: GROW VIA PHOTOSYNTHESIS IN THE SURFACE LAYERS OF THE OCEAN**
- **SLIGHTLY BUOYANT**
- **ABUNDANT (e.g. $10^5$ cells $ml^{-1}$)**

## PHYTOPLANKTON BIOMASS

**DEFINITION:**

**Biomass (B)** of phytoplankton is defined as the total weight (total numbers x average weight) of all the organisms in a given area or volume

ie it is the mass of the organisms/unit vol or unit area.

The equivalent term in fisheries is the "*stock size".*

**MEASUREMENT:**

**(1) As a mass of carbon per unit volume**

**(2) As a mass of photosynthetic pigment per unit volume**

## PHYTOPLANKTON BIOMASS

**MEASUREMENT:**

**(1) As a mass of carbon per unit volume or per unit area**

**METHODS:**

Discrete water samples

- **Reference:** Tarran *et al.* (1999) DSR II Vol 46 No. 3-4: 655-676
- Microscopy
- Flow cytometry

Both methods require conversion factors for cell numbers to cell volume and cell volume to a mass of carbon

**Typical oceanic range (per unit volume):** 10-60 μg C $l^{-1}$
**Typical oceanic range (per unit area):** 1-2 g C $m^{-2}$

## PHYTOPLANKTON BIOMASS

**MEASUREMENT**

**(2) As a mass of photosynthetic pigment per unit volume or per unit area:**

**Typical oceanic range (per unit volume):**

**0.01-2 μg Chl a $l^{-1}$ (mg Chl a $m^{-3}$)**

**Typical oceanic range (per unit area):**

**10-70 mg Chl a $m^{-2}$**

**METHODS:**

**Discrete samples (~500mls - 1 litre):**

- **High Performance Liquid Chromatography (HPLC)**
- **Spectrophotometry/fluorometry**

**Continuous samples:**

- **Fluorescence - sensor attached to:**

  **Towed/undulating instrument :- 2D profiles of fluorescence**

  **CTD :- 1D vertical profiles of fluorescence**

- **Remote Sensing of Ocean Colour**

## PHYTOPLANKTON BIOMASS

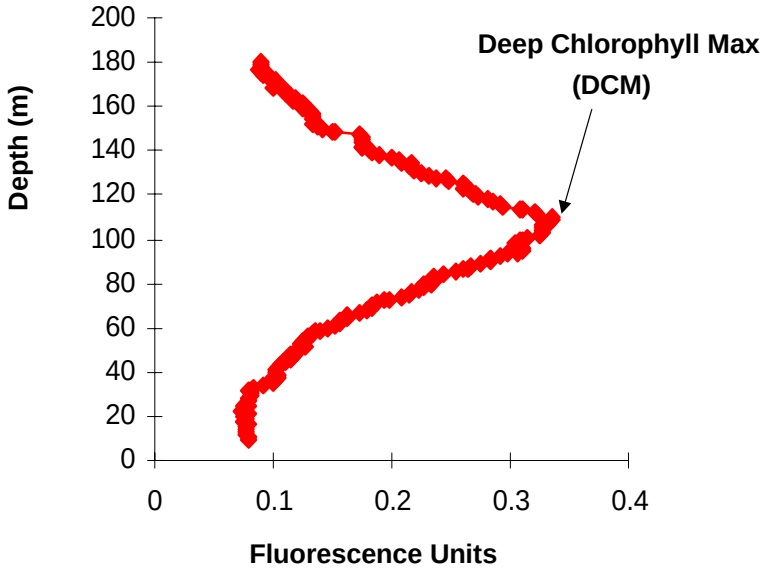
**MEASUREMENT**

- **Fluorescence - sensor attached to CTD:-**

**1D vertical profiles of fluorescence**

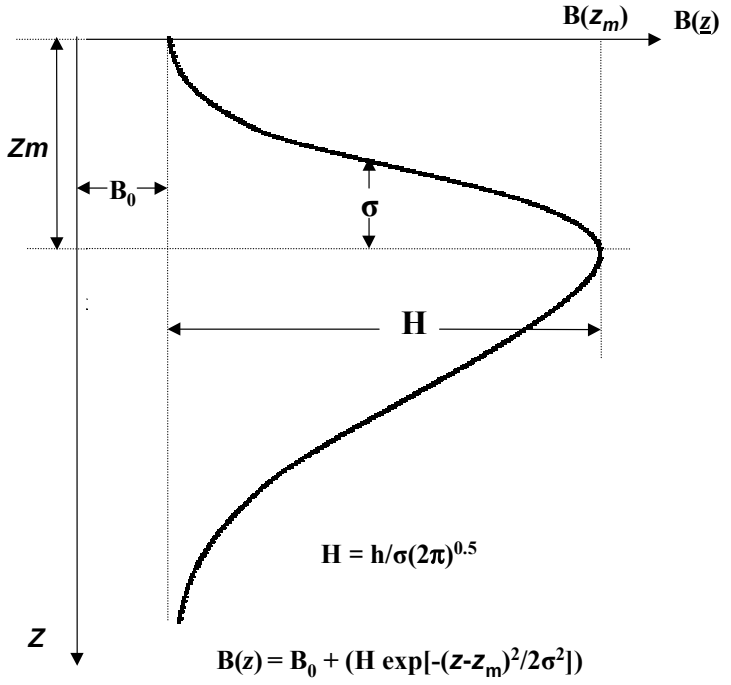
Requires calibration to chlorophyll-a concentrations from discrete measurements (HPLC, fluorometry, spectrophotometry)

**CTD Fluorescence Profile over Depth- July 1998, Azores Current region**




## MATHEMATICAL REPRESENTATION OF THE BIOMASS PROFILE: THE SHIFTED GAUSSIAN CURVE

**Ref:** Platt *et al.*(1988) DSRI, Vol 35, No.6: 855-879




**$B_0$ = the background pigment (mg $m^{-3}$)**

***Zm*** **= the depth of the chlorophyll peak (m)**

**σ = the standard deviation around the peak value (m)**

**h = the total pigment within the peak (mg $m^{-2}$)**

**H= the height of the peak above the background (m)**

## ESTIMATION OF CHLOROPHYLL-a BY REMOTE SENSING

**SeaWiFS** Ocean Colour Sensor - launched August 1997 and presently operational

Mounted on **NASA Seastar** satellite - polar orbiting satellite (sun-synchronous orbit at 705 km)

**Spatial Resolution:** 1km x 1km

**Temporal Resolution** - Global coverage every 48 hours

Data includes **water-leaving radiance data** at 6 wavelengths:

412, 443, 490, 510, 555, 670 nm

Sensor corrections (stray light) and atmospheric corrections (aerosol determination) are required to correct these signals

Bio-optical algorithms can then be applied to the water leaving radiances.

## ESTIMATION OF CHLOROPHYLL-a BY REMOTE SENSING

**BIO-OPTICAL ALGORITHM PRESENTLY USED FOR CONVERSION OF SeaWiFS DATA TO CHLOROPHYLL-a DATA:**

**Latest update on this algorithm was May 2000, based on the SeaBAM dataset (O' Reilly *et al.* (1998) *J Geophys. Res*, 103, No. C11: 24937-24953**

**This algorithm is called the OC4 Version 4**

**Coefficients for OC4 version 4 (Maximum Band Ratio, 4th Order Polynomial):**

**a = [0.366,-3.067,1.930,0.649,-1.532]**
**R = LOG10((Rrs443>Rrs490>Rrs510)/Rrs555)**
**Chl a (ug/l) = 10.0^(a(0) + a(1)*R + a(2)*R^2 + a(3)*R^3 + a(4)*R^4)**

## PRIMARY PRODUCTION

**DEFINITION:**

Primary production is the ***rate of production of phytoplankton***. In other words it is the amount of inorganic carbon assimilated by phytoplankton via the process of photosynthesis in a given volume of water over a given time period.

**Typical oceanic range (per unit volume):**
10-100 mg C $m^{-3}$ $day^{-1}$
**Typical oceanic mean value (per unit area):**
75 - 1000 mg C $m^{-2}$ $day^{-1}$

**MEASUREMENT:**

There are two principal, established groups of techniques:

***In Vitro:*** Samples enclosed in containers; uses isotopic tracer techniques; sample size millilitres to litres; experiment time is from one to a few hours

***Bulk Property****:* Based on changes in the chemistry of the water where the water is not physically enclosed. Experiment time is from one day to several years

## DAILY PRIMARY PRODUCTION

**MEASUREMENT:**

Conventional method used is the *In Vitro*: **$^{14}$C isotopic tracer technique:**

Originally described by Steeman Nielsen (1952)

Recent reference: Savidge and Gilpin (1999) DSR II 46: 701-723

**PROTOCOL:**

**Pre-dawn CTD cast:**

•Water samples (e.g.120ml) collected from a no. of depths of known light (PAR) intensity

•Triplicate samples and one dark bottle from each depth

•Typically 10-20µcCi $^{14}$C bicarbonate tracer added to each bottle

•Samples incubated for 24 hours: *In situ* or on-deck incubations

•Filtration after 24 hours

•Addition of scintillation cocktail to filter paper and measurement of counts, in disintegrations per minute made using a scintillation counter

•Counts converted to carbon fixed per unit time

## WHAT MAKES PRIMARY PRODUCTION CHANGE?

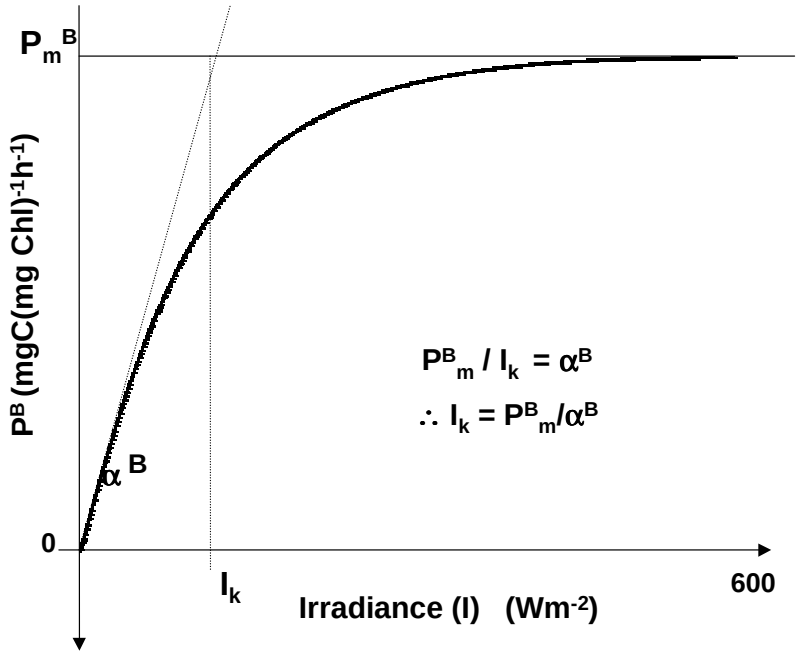
- THE LOCAL PHYTOPLANKTON BIOMASS CONCENTRATION
- THE INTENSITY AND DURATION OF SUNSHINE
- THE INTENSITY OF TURBULENCE IN THE WATER
- THE CONCENTRATION OF NUTRIENTS IN THE WATER
- THE TEMPERATURE
- THE KIND OF PHYTOPLANKTON PRESENT

## LIMITATIONS OF SHIPS FOR DATA COLLECTION

- SLOW SPEED OF THE VESSEL
- POOR “PERIPHERAL VISION”
- TIME REQUIRED TO MAKE THE MEASUREMENTS
- EXPENSE OF REPEAT COVERAGE

IDEAL IS TO CONVERT OCEAN SURFACE BIOMASS DISTRIBUTION OBSERVABLE FROM SPACE TO PRIMARY PRODUCTION.

## PHOTOSYNTHESIS-LIGHT CURVE (P-I CURVE)




**Note: $P^B$ = P/B = Primary production normalised to B**

**$P^B_m$ = Maximum assimilation number (normalised to B)**
**Typical oceanic range: 1 - 25 mg C (mg Chl a)$^{-1}$ h$^{-1}$**

**$\alpha^B$ = Initial slope**
**Typical oceanic range: 0.05 to 0.5 mg C (mg Chl a)$^{-1}$ h$^{-1}$(W m$^2$)$^{-1}$**

**Note: $I_* = I/ I_k = \alpha^B I/ P^B_m$**
**where $I_*$ = the nondimensional, or scaled irradiance**

## PHOTOSYNTHESIS-IRRADIANCE EXPERIMENTS

### MEASUREMENT:

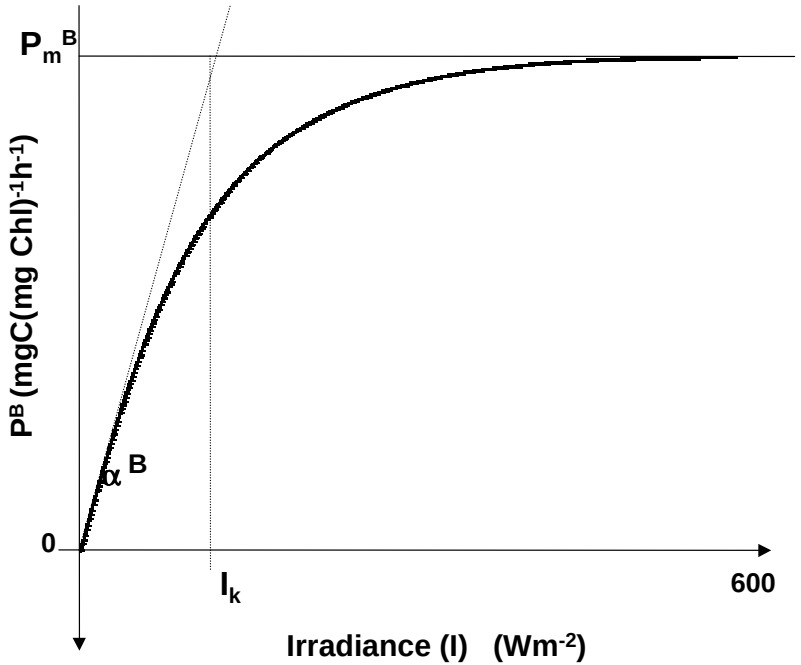
Conventional method used is the *In Vitro*: $^{14}$C isotopic tracer technique:

For a recent description: Sathyendranath *et al* (1999) DSR II (46): 633-653

### PROTOCOL:

- Water samples (e.g.100ml) collected from a pre-determined depth at a pre-determined time
- Typically 30 light bottles and three dark bottles from each depth
- Typically 40µCi $^{14}$C sodium bicarbonate tracer added to each bottle
- Samples incubated for 3 hours in a measured light gradient (e.g.0 to 600 Wm$^{-2}$)
- Filtration after 3 hours
- Addition of scintillation cocktail to filter paper and measurement of counts, in disintegrations per minute made using a scintillation counter
- Counts converted to carbon fixed per unit time

## MATHEMATICAL REPRESENTATION OF THE PHOTOSYNTHESIS-LIGHT CURVE




$P^B_m$ = Maximum assimilation number (normalised to B)
$\alpha^B$ = Initial slope

The P-I curve can be represented by an equation of the form:

$$P^B = p(I; \alpha^B, P^B_m)$$

## MATHEMATICAL REPRESENTATION OF THE PHOTOSYNTHESIS-LIGHT CURVE

General form: $P^B = p(I; \alpha^B, P^B_m)$

Accommodating depth (z) and wavelength ($\lambda$) effects:

- I intensity decreases with depth (attenuation). The spectral distribution of I also changes with depth

- $\alpha^B$ - often increases with depth
- $\alpha^B$ is strongly dependent on $\lambda$ :- Action Spectrum

- $P^B_m$ - generally decreases with depth
- $P^B_m$ is assumed to be spectrally neutral

**THE P-I CURVE CAN NOW BE DESCRIBED BY AN EQUATION OF THE FORM:**

$$P^B(z) = p(I(z,\lambda); \alpha^B(z,\lambda); P^B_m(z))$$

***NOTE: THIS EQUATION FORMS THE BASIS OF THE SPECTRAL VERSION OF THE PRIMARY PRODUCTION MODEL DESCRIBED IN THE NEXT LECTURES***

## THE PHOTIC ZONE AND PHOTIC ZONE DEPTH

**Definition: Photic zone**

The illuminated zone within the uppermost part of the water column, where the intensity of solar radiation is sufficient for net photosynthetic production to occur.

**Definition: Photic zone depth ($Z_p$)**

Often defined as the depth where the irradiance is reduced to 1% of its value in the surface.

Sometimes defined as the depth where the irradiance value is 0.1% of the surface irradiance

Photic zone depth varies with location

**Measurement:**

Spectroradiometry – can measure spectral distribution of the underwater light field - upwelling, downwelling irradiance at particular wavebands and/or over PAR

**Typical oceanic values: $Z_p$ ~ 50m to 150m**

## MATHEMATICAL REPRESENTATION OF THE PHOTIC ZONE

**Underwater light is attenuated with increasing depth:**

$$I(z) = I(0)e^{-KZ} \qquad \text{(Kirk, 1994)}$$

**where:**

**$I(z)$ = the PAR available at depth $Z$ ($Wm^{-2}$)**

**$I(0)$ = the PAR available at the surface ($Wm^{-2}$)**

**K = the diffuse vertical attenuation coefficient of PAR ($m^{-1}$) defined as the *rate of decrease* of light per unit distance in the water column**

**By definition:**

$$I(z_p) / I(0) = 0.01 = e^{-KZp}$$

**Where: $z_p$ = Photic zone depth**

$$\text{Ln } 0.01 = -KZ_p$$

$$\therefore 4.6/K = Z_p$$

**Note: K (over PAR) can be estimated if $Z_p$ is known**

## SUMMARY OF LECTURE 1

**AIM: TO ACT AS A BASIS FOR LECTURES 2 & 3**

**WE HAVE CONSIDERED:**

- **The requirement of methods for estimating pp particularly on large, ocean-basin scales: role of oceans in global climate processes and fisheries**

- **PROCESSES AND PROPERTIES RELEVANT TO MODELLING PRIMARY PRODUCTION:**

  - **Properties of oceanic phytoplankton**
  - **Phytoplankton biomass: the index taken to represent it, its measurement and mathematical representation for input into the PP models (BIOMASS PROFILE)**
  - **Primary production: its measurement and temporal and spatial variability. Required for MODEL VALIDATION**
  - **The P-I curve: its measurement and mathematical representation for input into the pp models (P-I PARAMETERS)**
  - **The photic zone depth: its measurement and mathematical representation for input into the PP models (Zp, K)**