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Modeling the effect of light on phytoplanktonic growth dynamics : A Review

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Introduction

Light plays an important role in the life of organisms including the whole diversity of plants ranging from microscopic phytoplankton to giant trees, because it is the sole source of energy which effects the growth dynamics and structure of most aquatic and terrestrial communities. The unidirectional nature of light gives rise to a vertical gradient of light intensity as a function of depth. Since phototropic organisms absorb light to make a living, this vertical gradient is not static but dynamic. (Reynolds, 1984).

Turbidity and transparency are the major factors in water column, which affects the growth of phytoplankton, because light penetration is controlled by the amount and kind of materials that are dissolved and suspended in the water. Two processes diminish light under water column: absorption and scattering (Kirk, 1994). Absorption and scattering interact in a complex and nonlinear manner to govern the attenuation of light under water .The equation governing the propagation of light underwater, called the radiative transport equations, have no exact solution: but several computer programs have been written to solve the equations by various numerical methods.

Light limited growth models

It's seems that Kok (1952) and Sverdrup (1953) used mathematical models for the first time about five decades ago. There after a number of models were suggested to study the problem and for an excellent discussion on various models, One may refers to Talling (1957), Platt *et al*. (1990), Kirk (1994), Huisman, and Wessing (1994), Huisman (1999),etc.Light- limited growth models use mathematical and numerical techniques to simulate the physical and biological processes that affect the growth dynamics of phytoplankton. A comprehensive light limiting growth modeling approach require the following component:

(a) Physico- chemical and biological data.
(b) Basic equation governing light behavior.

(A) Physico- chemical and biological data.

Physico-chemical and biological parameters plays an important role in population dynamics of phytoplankton. Various parameter that effects the population dynamics of phytoplankton may be broadly classified as light intensity, photoperiod, nutrient availability, Chlorophyll content, transparency, turbidity, temperature, velocity, water column depth. Light intensity, duration, and water column depth are the basic parameter and others are the derived ones.

(B) Basic equations governing light behaviour.

Light downwelling in water column is expressed by two basic exponential equation:

(i) The Beer-Lambert law

(ii) Bouguer's law.

The attenuation of light due to absorption and scattering along the path at a distance S is given by the equation:

$$L(s) = L(0)e^{-\int_0^s K(s)ds} = L(0)e^{-KS}$$

Where K(s) is a function of local parameters of the medium, and Ks =is the opacity or optical thickness.

The light intensity, I, decreases with depth S according to Lambert- Beer's law:

$$I(s) = I_{in}e^{-(kws+k_{bg}s)}$$

Where I_{in} is the incident light intensity, k is the specific light attenuation coefficient of the phytoplankton, and K_{bg} is the total background turbidity due to non- phytoplankton components. The light intensity at the bottom of the water column, I_{out}, is given by I_{out}= I(Z).

Depth integrals are used to calculate depth- integrated production by Monod equation:

$$P(I) = \frac{P_{\max}I}{(P_{\max}/\alpha)+I}$$

Where $P_{mex}$is the maximum rate of specific production, and is the slope of the P(I) function at I =0 .The advantage of the Monod equation is that it has a simple analytical solution of its depth integral.

Combining the Beer-Lambert's law of absorption and Monod Equation, the following dynamic system (Huisman and Weissing 1994, Weissing and Huisman 1994).

$$\frac{dw}{dx} = \frac{1}{z}\frac{Kw}{(Kw+K_{bg})}\int_{I_{out}}^{I_{in}}\frac{p(I)}{kI}dI - Dw$$

Where P(I) is a function of the local light intensity I. This model predicts that there is a critical value of I_{out}, where we have called the critical light intensity, at which the phytoplankton population should remain stationary. The phytoplankton population should increase as long as I_{out} is above its's critical light intensity, where as the population should decrease as soon as I_{out} is below its critical light intensity. These population dynamics leads to a steady state. A phytoplankton popupation should grow unite, at steady state, it has reduced the light intensity at the bottom of the water column to its critical light intensity.

The light resource index for phytoplankton growth can be given as (Hamiliton and Schladow, 1997):

$$R_I = \frac{I}{I_{sat}} \exp\left[1 - \frac{I}{I_{sat}}\right]$$

Where I = light irradiance in a stationary water zone(STA-WZ) with its saturation value for reproduction as I_{sat}.

Steele's Equation (1962):

$$F_{Lp} = \frac{I(Z)}{K_{Lp}} e^{1-\frac{I(z)}{K_{Lp}}}$$

where K_{Lp} = the PAR at which phytoplankton growth is optimal [ly/d]. This function can combined with the Beer-Lambert law and integrated over water depth to yield

$$\phi_{Lp} = \frac{2.718282}{K_e H}\left[e^{-\frac{I(0)}{K_{Lp}}e^{-K_e H}} - e^{-\frac{I(0)}{K_{Lp}}}\right]$$

Smith's Function(1980):

$$F_{Lp} = \frac{I(z)}{\sqrt{K^2{}_{Lp} + I(z)^2}}$$

where KLp = the Smith parameter for phytoplankton [ly/d]; that is, the PAR at which growth is 70.7% of the maximum. This function can be combined with the Beer-Lambert law and integrated over water depth to yield. FLp = phytoplankton growth attenuation due to light and KLp = the phytoplankton light parameter.

$$\phi_{Lp} = \frac{1}{k_e H} In\left[\frac{I(0)/K_{Lp} + \sqrt{1+\left(I(0)/K_{Lp}\right)^2}}{\left(I(0)/K_{Lp}\right)e^{-k_e H} + \sqrt{1+\left((I(0)/K_{Lp})e^{-k_e H}\right)^2}}\right]$$

Light intensity and phytoplanktonic modeling

Various types of model are developed in past few decades. Models which are developed for light intensity and its effect on phytoplankton growth are based on some basic assumptions such as Lambert-Beer's law, Steele's equation and Smith's equation for light and its behavior in absorbing and scattering column and Monod equation for the depth integration,

The specific light transmission coefficient, k was given by Bindloss(1976). Reynolds(1984) gave the growth rate models for phytoplankton in presence of light.George and Edwards(1976) gave the model for surface distribution of phytoplankton chlorophyll. Huisman and Weissing (1994. 1995), and Weissing and Huisman (1994) developed an analytically tractable model to analyze the effects of a dynamic light gradient on phytoplankton competition and community structure. Kok (1952), Sverdrup(1953) assume to be the founder of light intensity and its effect on the phytoplanktonic growth dynamics .Cullen (1990) developed a model on the growth and phototosynthesis in phytoplankton.Talling (1957), Platt *et al*.(1990), Kirk (1994) also developed some dynamic model for light and phytoplanktonic population growth.Numerical expressions for approximation for depth integral is also given by Platt *et al*. (1991).Several investigators Talling(1965), Jewson (1977), Reynolds(1984).Chapra(1997) have used the concept of a euphotic depth to calculate phytoplankton carrying capacities under light- limited conditions and also summarized the equation to give the model for phytoplankton and its growth limited by light. Jassby and Platt(1976) formulate a mathematical model for the relationship between light and phytoplankton. Kemp and Mitsch (1979) gave a general model for phytoplankton.Evers (1991) developed a model for light-limited continuous cultures for plankton.

Symbol		Interpretetion	Unit
S	=	Depth of the water column.	m.
z	=	Total depth of water column.	m.
w	=	Biomass of water column.	g/m_2.
W	=	Total biomass of the water column.	g/m_2.
I	=	light irradiance.	$J.m^{-2}.s^{-1}$
I_{in}	=	is the incident light intensity,	$J.m^{-2}.s^{-1}$
k	=	is the specific light attenuation coefficient of the phytoplankton.	$m^{-1.}$
K_{bg}	=	is the total background turbidity due to non- phytoplankton components.	$m^{2.} g^{-1}$.
I_{out}	=	is the light intensity at the bottom of the water column.	$J.m^{-2}.s^{-1}$
KLp	=	the Smith parameter for phytoplankton.	ly/d.
FLp	=	phytoplankton growth attenuation due to light.	$m^{-1.}$
K(s)	=	is a function of local parameters of the medium.	_
Lp	=	the phytoplankton light parameter.	_
I_{sat}	=	saturation value for reproduction.	_
P(I)	=	is a functin of the local light intensity.	_
P_{mex}	=	is the maximum rate of specific production.	1/s

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