Int. J. Environ. Res., 3(2):223-228, Spring 2009
ISSN: 1735-6865

Effect of the Euphotic Depth and Mixing Depth on Phytoplanktonic Growth Mechanism

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Received 14 March 2008; Revised 25 Dec 2008; Accepted 5 Jan. 2009

ABSTRACT: Light is never being distributed homogeneously and it forms a gradient over biomass. The unidirectional nature of light gives rise to a vertical gradient of light intensity as a function of depth. The maximum depth of the light zone suitable for phytoplankton photosynthesis is designated as the euphotic depth. This study was designed to test the hypothesis of mixing depth of phytoplankton and its compensation depth. In a water column undergoing turbulent mixing, where phytoplankton cells are around by the fluid motion, the irradiance encountered by cells will be a function of the ratio between the euphotic depth (z_y) and the depth of mixing (z_m). During the course of study the z_y/z_m ratio value were observed in the range of 0.4427 to 3.242. However, identification of Compensation point values for z_y/z_m indicates that light conditions are suitable for net phytoplankton production, because the mean value (0.3413) was good for the phytoplanktonic growth, which was greater than the minimum 0.20 limit.

Key words: Mixing depth, Phytoplankton, Compensation depth, Euphotic depth, Biovolume

INTRODUCTION

Planktons are primary producers responsible for a large part of the Earth's global primary photosynthetic production. These organisms are thus the objects of intensive multidisciplinary studies at different levels of organization, from molecular genetics and physiology to population dynamics and community ecology. The success of these photosynthetic organisms lies in their ability to use solar energy and nutrients and to cope with a fluctuating environment. Thus, light, nutrients, and water mixing plays a key role in the evolution of their life history traits, their physiology and their ecology. The present study deals with the test of the hypothesis of mixing depth of phytoplankton and its compensation depth. Moreover, in recent decades, ecologists have considered to an increasing extent their interactions with other biological communities, as herbivores or decomposers. Biotic factors appear indeed to play a determinant role in the physiological characteristics, adaptive strategies, and dynamics of primary producers. Estimation of phytoplankton assemblage structure can provide a number of useful indications, on the functioning of an aquatic ecosystem, because the growth is related to the light intensity and either background particles (Living or non living) in the water ecosystem. According to Gordan (1989), Lambert- Beer's law provides a fairly good approximation in aquatic environments. Cullen and Lewis (1988), investigate that the photosynthesis parameters will vary when algae adapt to changes in light availability during vertical mixing. Light limited growth models use mathematical and numerical techniques to simulate the physical and biological processes that affect the growth dynamics of phytoplankton (Khanna *et al.*, 2005). The importance of light in water column is very much studied by different workers around the World (Hansen and Hubbell, 1980, Rhee and Gotham, 1981, Tilman and Sterner, 1984). Ecological interactions including photosynthesis and primary productivity have been the subjects of some work on deterministic modeling of streams (Kelly, 1975, Stehfest, 1977). Reynold (1999) reviewed the conceptual models

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and its problem with special reference to phytoplankton. Phytoplankton succession is a well-investigated phenomenon in aquatic ecology and several studies have described the patterns and underlying mechanisms of the dynamics (Sommer *et al.,* 1986; Marshal and Peters, 1989; Vanni and Temte, 1990; Hansson *et al.*, 1998; Rothhaupt, 2000; Huisman, *et al.*,1999). To have a better understanding of the factors responsible for changes in the distributive pattern of phytoplankton, it is important to understand the link between changes in environmental parameters and phytoplankton dynamics.

MATERIALS & METHODS

The study was performed on a monthly basis for one year at two different sampling stations of river Suswa. In the present study photosynthetically active radiation profiles (PAR), was measured by Lux meter (Model ESCORP [TES-1332]) and was then converted into unit μ moles m^{-2} s^{-1} using conversion factor $\mu molm^2 s^{-1} = Lux \times 0.14$. A 20 cm diameter secchi disc was used to measure the secchi depth (E_z). While the PAR light attenuation coefficient k (m^{-1}) was calculated according to Sverdrup (1953) using Secchi disc depth (E_z) by applying the formula $\frac{1.7}{E_z}$.

Since the water column was permanently mixed, subsurface water samples were taken with a Van Dorn type sampler suspended solids (SS) were performed according to APHA (1998). Phytoplankton samples were collected at both stations for taxonomic identification and were preserved in acid iodine solution (Lugol's) and stored in glass vials. Sedgwick-Rafter counting chambers (50mm x 20mm) were approached for estimating phytoplankton numbers. Fixed sub samples were analyzed under inverted microscope equipped with contrast illumination: 10X, 40X, and 100X objectives; 10X eyepieces and micrometer eyepieces (graduated in μm).

The cell biovolume and surface area were calculated based on geometric shapes and the average of the microscopic dimensions of 10–30 organisms per taxon (Hillebrand *et al.*, 1999). The classification system of Van Den Hoeck et al. (1995) was followed for Classes and Divisions. Krammer and Lange-Bertalot (1986, 1988, 1991), Tomas (1997), and Round et al. (1992) were used as main taxonomic references for genera. Total biovolume (V) was computed from measurements of abundance (n) and estimates of cell volume (v) (Jun and Liu, 2003):

$$V = \sum n_i v_i$$

Where n_i =abundance of genus
I= v_i volume for genus i.

The chlorophyll biomass (Chl') was estimated using the formula sited in Li and Dickie (2001).

$$Chl' = \sum n_i \frac{\left[0.433(v_i)^{0.863}\right]}{40}$$

The maximum depth of the light zone suitable for phytoplankton photosynthesis is designated as the euphotic depth (z_y), and is estimated as the depth where light energy is reduced to 1% of the intensity immediately below the water surface. The depth of the euphotic zone can be calculated from the equation:

$$z_y = \frac{In100}{k} = \frac{4.6052}{k}$$

In a water column undergoing turbulent mixing, where phytoplankton cells are around by the fluid motion, the irradiance encountered by cells will be a function of the ratio between the euphotic depth (z_y) and the depth of mixing (z_m). If z_m is equals to $z_{y\ i.e}$. z_y/ z_m=1 then the cells are constantly illuminated and photosynthesis is continuous during the daylight period. If the mixing depth is greater than the depth of the light zone then the phytoplankton spend a proportion of their daylight period in the dark where photosynthesis cannot occur but respiration continues. As the z_y/z_m ratio further decreases, the proportion of time that the cells spend in the light is reduced until eventually net growth cannot occur because respiratory carbon use equals or exceeds the carbon supply from photosynthesis.A number of models have been developed to calculate the daily rate of photosynthesis integrated over the depth of light penetration ($\sum$ P), but model proposed by Talling (1957) is used here.

$$\sum P = bP_M T\left(\frac{In\left(\frac{Ii_o}{0.5I_k}\right)}{k}\right)$$

Where $\sum P$ is the carbon fixed under unit surface area per day, and b is the Chlorophyll concentration (mg m^{-3}), P_M is the maximum Chlorophyll specific rate of photosynthesis (mg C mg Chl^{-1} h^{-1}), k is the vertical light attenuation coefficient (m^{-1}), T is the length of the daylight period (hours), Ii_o is the mean daily irradiance just below the water surface (μ moles m^2 s^{-1}), and I_k is the light intensity below which photosynthesis becomes increasingly light limited (μ moles m^2 s^{-1}).The daily respiration rate integrated over the mixing depth and expressed as a rate per unit of surface area is given by the equation:

$$\sum R = 24bRz_m$$

Where $\sum R$ is the carbon respired under unit surface area per day. R is the Chlorophyll specific rate of respiration (mg C mg chl^{-1} h^{-1}).The column compensation point is defined as the mixing depth that result in the daily integral photosynthesis balancing the daily integral respiration:

$$\sum P = \sum R$$

Using this equation and replacing k with the equivalent *In* 100/z_y gives the ratio of the euphotic depth (z_y) to mixing depth (z_m) that results in daily photosynthesis balancing daily respiration:

$$\frac{z_y}{z_m} = \frac{24RIn100}{\left(P_M TIn\left(\frac{Ii_o}{0.5I_k}\right)\right)}$$

This equation can be simplified by assuming that respiration rate R which is constant and equivalent to $0.1P_M$ (Reynolds, 1984) and that the function $In\left(Ii_o / 0.5I_k\right)$ is equal to a mean value of 2.75 (Reynolds, 1984) to given by:

$$\frac{z_y}{z_m} = \frac{4.02}{T}$$

RESULTS & DISCUSSION

The dependency of phytoplankton population changes on the z_y/z_m ratio was used to assess the likelihood that heights turbidity in the river Suswa resulted in light limitation of phytoplankton production, and to indicate the increased growth (Fig. 1). Direct measurements of the mixing depth were not made and so it was estimated as the maximum depth of the sampling sites (Fig. 2). The depths of the two sampling sites of river Suswa were 1.5m at Sampling station A (Satyanarayan Area) and 1.2m at Sampling station B (Downstream Vedic Nagar). The calculated z_y/z_m ratio changed considerably over time (Figs. 3 & 4), but for 100% of the 12 month study period it was much higher than 0.2, the minimum value of the critical range set for the z_y/z_m ratio, indicating that light limitation was not considered. The exceeded ratio of z_y/z_m (0.35) indicates that the light was sufficient for phytoplanktonic growth during sampling period. In the months of March to June the maximum z_y/z_m ratio were observed which indicate the maximum growth of the phytoplankton.During the course of study the z_y/z_m ratio value were observed in the range of 0.4427 to 3.242.

The column compensation point is defined as the mixing depth that results in the daily integral photosynthesis balancing the daily integral respiration. The day length meanly affects it. If the length T is 12 hours, then at the column compensation point z_y/z_m has a value of 0.33. A respiration rate of $0.1P_M$ is relatively high and an

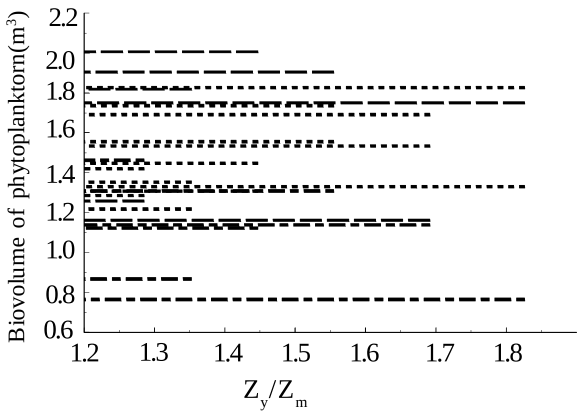

Fig.1. Showing different values of z_y/z_m ratio (at x axis) and Biovolume of Phytoplankton at y axis (m^3) the regression equation for three different seasons was $Ratio = 1.97 - 0.399\,phy$ **with$DF_{1,4}$ =5, S=0.198, r^2 = 0.259**

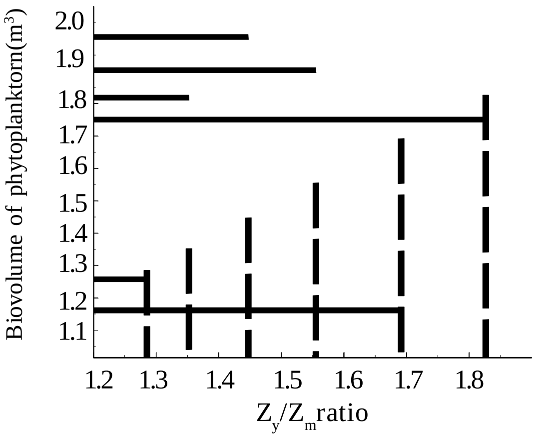

Fig. 2. Showing mean values of z_y / z_m ratio (to y axis minimum) and Biovolume of Phytoplankton (to x axis minimum) of two different sampling site. The regression equation for three different seasons was $Ratio = 1.54 - 0.010Phy$ **with $DF_{1,4}$ =5, S=0.230, r = 0.911, T=0.164 at 95% confidence level**

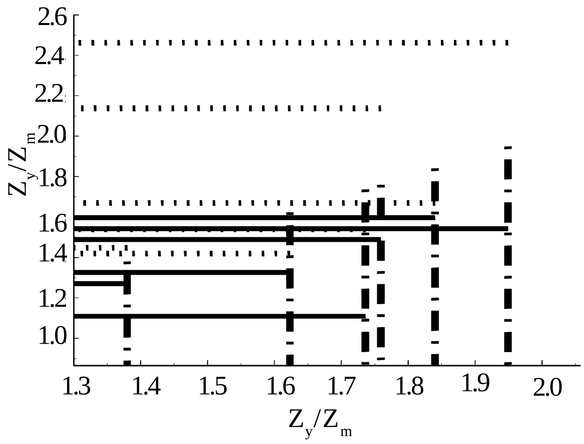

Fig. 3. Line on y axis (to x axis minimum) with dot showing the value of z_y/z_m ratio form March to June (Summer, C_1); line continuance on y axis (to x axis minimum) shows the value of z_y/z_m ratio from July to October (rainy, C_2) and line with dots (w = 6), on x axis (to y axis minimum) shows the value from November to February.(Winter, C_3) at Sampling station A The regression equation for three different seasons was $C_2 = 1.12 + 0.020C_3 + 0.176C_1$ **$DF_{2,3}$=5, F=0.09 ,S=0.234**

average value of 0.07 may be more appropriate (Reynolds 1984), reducing the critical z_y/z_m ratio for column compensation point to 0.23. The result shows the variation in compensation point of 0.281 to 0.434 with mean value of 0.3413 (n =18).

In assessing the effect of reduced light penetration on phytoplankton growth the depth of the euphotic Zone was compared with the maximum depth of the river rather than the mixing depth because we already taken this consideration. This approximation was made to calculate compensation depth for which estimation of mixing depth is essential. The assumption that the mixing depth is equivalent to the maximum depth of the water column may be reasonable for much of the time as water of the river Suswa was well mixed. Firstly we compare the biovolume, which was taken in place of biomass of the phytoplankton with the ratio of z_y/z_m (Fig.1). with increase in the value of z_y/z_m ratio there was considerable increase in phytoplanktonic biovolume ($DF_{1,4}$ =5, S=0.230, r = 0.911, T=0.164.) indicating the growth of phytoplankton (Fig.2). The z_y/z_m ratio also provides a reasonable estimation of the relative proportion of the population (in form of biovolume) that is within the euphotic zone, in case the vertical movement of the cells is minimized. Despite of many assumption made in setting the value of compensation point there was significant increase in concentrations of phytoplankton, which was always associated to the value of the ratio equal to or greater than the 0.281 to 0.434 (Fig. 5). The availability of light is significant through out the sampling period i.e. light availability is more than standard ratio (0.33). There were major changes in the value of z_y/z_m ratio, which indicates the

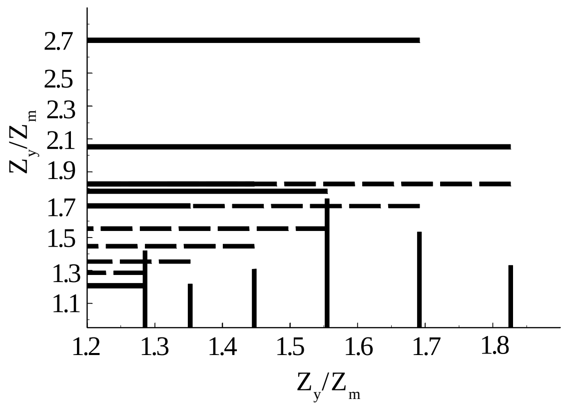

Fig. 4. Continuance line on y axis (to x axis minimum) showing the value of z_y/z_m ratio form March to June (Summer, C_1); dotted line on y axis (to x axis minimum) shows the value of z_y/z_m ratio from July to October (rainy, C_2) and continuance line, on x axis (to y axis minimum) shows the value from November to February. (Winter, C_3) at Sampling station B The regression equation for three different seasons was $C_2 = 0.35 - 0.159C_3 + 0.63C_1$ **with $DF_{2,3}$ =5, S=0.279, F=0.15**

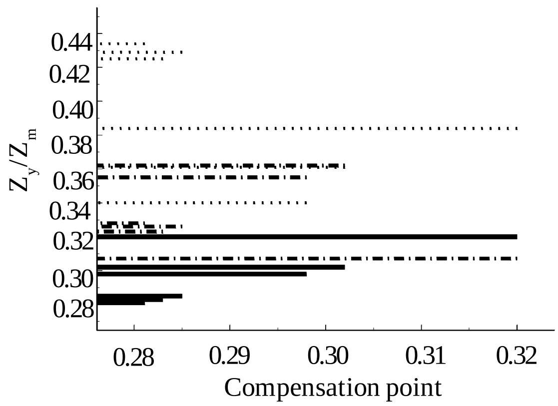

Fig.5. Showing the range of compensation point value on y -axis (to x axis minimum); March to June (Summer); with continuance line; from July to October (rainy) mixture of lines and dotes line, (-. -. -. -.) on y axis (to x axis minimum) the value from November to February. (Winter) with dotted line. The regression equation for three different seasons was $C_1 = 0.669 - 0.598C_2 - 0.444C_3$ **with** $DF_{2,3}$ **=5, S=0.008,** r^2 **=0.825 at 95% confidence level**

decrease in phytoplanktonic growth. But the value of z_y/z_m ratio was low (0.4427) in the months of November to February (winter).However, identification of Compensation point values for z_y/z_m indicates that light conditions are suitable for net phytoplankton production, because the mean value (0.3413) was good for the phytoplanktonic growth, which was greater than the minimum 0.20 limits. Because the latitudinal and altitudinal variation effects the day length and both the two sampling station are situated approximately at same latitude and altitude there were no such differences in compensation point at both the sampling station.

CONCLUSION

From the above study it may be concluded that light is the sole energy source for nearly all plant species, ranging from the tiny phytoplankton to giant sequoia tree. As a consequence, the availability of light has a major impact on the dynamics and structure of the most aquatic and terrestrial communities. Light differs from all other resources because it cannot be mixed. Certain dissolved and particulate substances create the light gradient. The optically important water quality parameters are dissolved solid and suspended solid.

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