A COEFFICIENT RELATING TO THE PHYTOPLANKTON IN THE SEA*

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ABSTRACT

The changes in the phytoplankton crop of the sea have been viewed from a physical stand-point. A coefficient has been developed which is related to the quantity of phytoplankton in the sea. The changes in the coefficient are related with the supply of nutrients and the availability of sunlight. The nutrient and optical conditions required for optimal occurrence of the coefficient have been derived. It is further inferred that the optimal occurrence of the coefficient takes place at relatively great depths for relatively clear waters. In case of turbid waters, the optimum is very close to the sea surface.

INTRODUCTION

ABOUT nine-tenths of the food of the ocean is provided by the microscopic plants, the diatoms which occur in large numbers in the plankton (Balakrishnan Nair, 1970). Most of the production lies within the euphotic zone and there is a gradual decrease until the extinction of the phytoplankton at the beginning of the aphotic zone. The greatest production, however, lies several metres below the surface (Davis, 1955).

It is well known that sunlight and dissolved nutrients are essential for the growth of the phytoplankton. The changes in the phytoplankton crop of the sea have been viewed from a physical point of view.

A COEFFICIENT RELATING TO THE QUANTITY OF PHYTOPLANKTON

Let Q be the phytoplankton 'density' (either the number of live cells per unit volume of sea water or the mass of live phytoplankton per unit volume) at level z at a given instant t. Let $Q + dQ$ be its value at the same level at time $t + dt$. The value of dQ does not include any changes in phytoplankton that are brought by advectional effects. The production, dQ, depends upon the time interval dt, the initial value of Q and also upon the availability of nutrients and light at that level. Thus it is reasonable to assume, to start with, that

$$dQ = k \ Q \ I \ c \ dt \qquad \ldots \qquad \ldots \qquad (1)$$

where I is the intensity of light, c is the concentration of dissolved nutrients and k is an arbitrary constant. From eq. (1),

$$\frac{dQ}{Qdt} = k \ I \ c \qquad \ldots \qquad \ldots \qquad (2)$$

The term, dQ/Qdt, may be described as "the coefficient of phytoplankton", G, which may be defined as the rate of change of phytoplankton per unit time produced by a unit amount of phytoplankton.

During the International Indian Ocean Expedition, R. V. ANTON BRUUN has made oceanographic and biological collections along two meridional sections passing through 70°E and 80°E during May-July, 1963 (Woods Hole Oceanographic Institution, 1964). The *in situ* values of C^{14}, chlorophyll *a*, sunlight intensities and inorganic phosphates at various depths are some of the data presented in that report. Fig. 1 is based on those data for stations 110 to 144, falling between latitudes 10°N and 40°S. The following points are noteworthy here. The *in situ* C^{14} values which are taken here for the time rate of production of phytoplankton, were obtained from sea water samples incubated for 24 hours on deck in water cooled cylinders
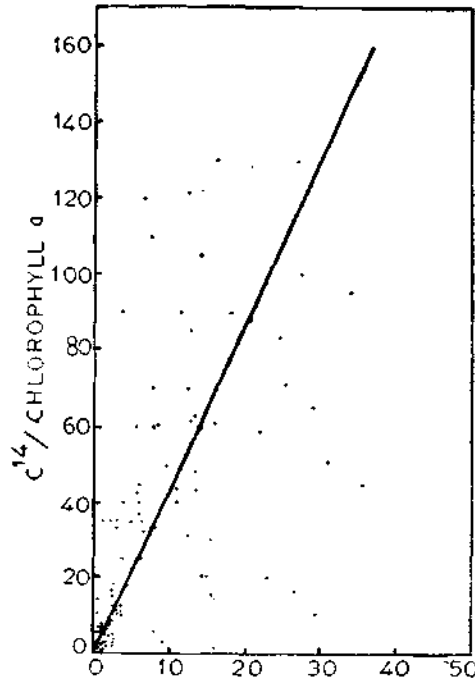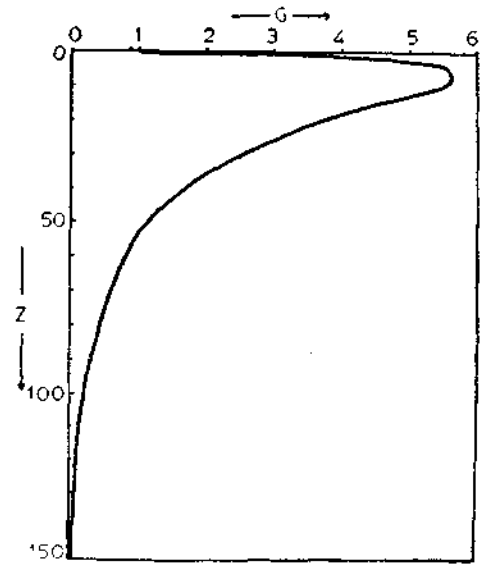

Fig. 1. Light intensity × PO_4.

Fig. 2. Variation of "G" with depth.

covered with suitable filters. There was much controversy as to what exactly is being measured by C^{14} method even though it has been made clear that in long-term experiments the net production is measured by the method (Ramachandran Nair, 1966). The chlorophyll *a* is taken as a measure of the phytoplankton crop. Phytoplankton is composed of diatoms, dinoflagellates, coccolithophores, silico-flagellates, cryptomonads, chrysomonads, green algae and blue-green algae (Bala-krishnan Nair, 1970). Chlorophyll *a* is contained only by the major groups of the phytoplankton. The advectional (both horizontal and vertical) processes and the bacterial action would affect the phosphate values during the day-long periods.

[2]

Now, coming to eq. (2), as I and c are functions of depth in the sea, it follows that G is also a function of depth. The general relation between I and depth z in the sea is given by (Murty, MS)

$$I = I_0 e^{-\propto Z^p} \qquad \qquad (3)$$

where I_0 is the intensity of sunlight at the sea surface and $\propto$ and p are positive constants (p = 1 for pure water and p $\approx$ $\frac{1}{2}$ for sea water in general).

For the mid oceans, the supply of nutrients to the upper layers of the sea is made by eddy diffusion processes from the deeper layers when organic matter gets decayed and converted into soluble inorganic substances by bacterial action. Phosphate and nitrate values at 1,000 m depth are of the order of 2-3 μg at/1 and 30 μg at /1 respectively (Sverdrup et al., 1954). Theirslopes are more or less alike in the upper 1,000 m. The phosphate concentration at the sea surface is abou 0.1 μg at /1 although the nitrate value ingeneral is zero at the surface.

The nutrient concentration c, at level z in the upper layers may be represented by

$$c = mz + c_0 \qquad \qquad (4)$$

where m is the increase of concentration per unit depth and c_0 is its value at the surface. Hence from eq. (2), (3) and (4)

$$G = k\ I_0\ e^{-\propto Z^p}\ (mz + c_0) \qquad \qquad (5)$$

The vertical variation of G, with reference to its surface value is presented in Fig. 2, for average oceanic water ($\propto$ = 0.8) while the values of m and c_0 are 1/150 and 0.001 respectively.

From eq. (5)

$$\frac{dG}{dz} = k\ I_0\ e^{-\propto z^p}\ (-\propto)\ p\ z^{p-1}\ (mz + c_0)$$
$$+ k\ I_0\ e^{-\propto z^p}\ m \qquad \qquad (6)$$

from which the depth where G is maximum is given by

$$\propto p z^{p-1}\ (mz + c_0) = m$$

i. e., $\qquad \propto\ p\ m\ z^p + \propto\ p\ c_0\ z^{p-1} - m = 0 \qquad \qquad (7)$

In case of pure water (p= 1), the depth corresponding to the maximum value of G is given by:

$$z = \frac{m - \propto. c_0}{\propto\ m} \qquad \qquad (8)$$

In case of sea water (p$\approx$$\frac{1}{2}$), the depth of maximum occurrence of G is governed by the relation

[3]

$$\frac{\alpha}{2} z^{-\frac{1}{2}}(mz+c_0) - m = 0$$

i. e., $\quad \alpha mz - 2mz^{\frac{1}{2}} + \alpha c_0 = 0 \qquad \qquad \ldots \qquad \ldots \quad (9)$

Let $z^{\frac{1}{2}} = x$, then

$$\alpha mx^2 - 2mx + \alpha c_0 = 0, \qquad \qquad \ldots \qquad \ldots \quad (10)$$

the solution being,

$$x = \frac{1}{\alpha} \pm \sqrt{\frac{1}{\alpha^2} - \frac{c_0}{m}} \qquad \ldots \qquad \ldots \quad (11)$$

Hence the depth in the sea corresponding to the maximum value of G is governed by:

$$z = \frac{2}{\alpha^2} - \frac{c_0}{m} \pm \frac{2}{\alpha}\sqrt{\frac{1}{\alpha^2} - \frac{c_0}{m}} \qquad \ldots \quad (12)$$

z would be real only when

$$\frac{1}{\alpha^2} - \frac{c_0}{m} < 0$$

i. .e. $\qquad \frac{m}{c_0 \alpha} \geq 1 \qquad \qquad \ldots \qquad \ldots \quad (13)$

When the nutrient concentration at the surface is negligible, eq. (9) gets simplified to

$$z = \frac{1}{\alpha^2} \qquad \text{or} \qquad \ldots \quad (14)$$

$$z = 0 \qquad \qquad \ldots \quad (15)$$

Under the above conditions, the depth of maximum occurrence of G for didfferent types of sea water (eq.14) may be readily obtained. Thus, for pure sea water ($\alpha=0.4$), $z=25$ m; clear oceanic water ($\alpha=0.5$), $z=16$ m; average oceanic water ($\alpha=0.8$), $z=6.2$ m; average coastal water ($\alpha=1.5$), $z=1.8$ m and turbid coastal water ($\alpha=1.9$), $z=1.1$ m. It is interesting to infer from this that the optimum occurrence of the coefficient, (G), takes place at relatively great depths for relatively clear waters, under the same conditions of nutrients. In case of turbid waters, the optimum is very close to the surface.

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