

The Effect of Intensity and Quality of Illumination on the Photosynthesis of some Tropical Marine Phytoplankton

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Abstract

Using solar energy as a source of illumination, photosynthesis in 11 species of marine plankton algae was studied as a function of light intensity. From the photosynthesis-light curve for each organism, the saturation points (I_k) in different organisms were determined. Among the diatoms and flagellates, the highest I_k (saturation point) values were found in *Rhizosolenia styliiformis* and *Dinophysis miles* respectively. When the organisms were exposed to a portion of the visible spectrum starting from 700 m μ , the photosynthesis was found to be related to the radiant energy. The missing portions of the spectrum produced no significant change in the rate of photosynthesis. The photosynthetic response shown by the different organisms was strikingly similar, which signifies that, despite the qualitative dissimilarities which the organisms may possess in their pigment composition, they are capable of much chromatic adaptation.

Introduction

From numerous investigations it has been deduced that all visible radiation, between the wavelengths 700 and 400 m μ , is utilized by phytoplankton for photosynthesis (Rabinowitch, 1956; Strickland, 1958). Although in some studies dealing with action spectra, the rate of photosynthesis at low light intensities has been found to be dependent upon wavelength (McLeod, 1960), the total amount of energy available at the wavelength is more important than the wavelength itself (Pickett and Myers, 1966). Within the euphotic zone, the phytoplankton organisms occurring at different depths are exposed to different intensity and spectral quality of light (Kinne, 1970). Precise information, therefore, on the relationship between photosynthesis and light conditions is of much value for determining the relative efficiency of utilization of light in the sea. In tropical marine phytoplankton, neither the intensity effect nor the spectral characteristics of light on photosynthesis have been adequately studied. In this series of experiments, we have used different organisms in cultures and have attempted to investigate the influence of a range of light intensity and spectral bands on the rate of photosynthesis.

Material and Methods

Unialgal, but not bacteria-free, cultures of 11 different organisms were grown in the laboratory in enriched sea water (Erdschreiber). Inocula from healthy cultures were resuspended in bottles containing Millipore-filtered sea water. The total volume of each bottle was 50 ml. In each bottle, 1 ml ^{14}C bicarbonate solution of 0.4 μC was added and the bottles were clamped in an incubator of the type described by Steemann Nielsen (1963). The incubator had a revolving wheel divided into 10 equal compartments for the bottles to be clamped firmly. Precalibrated neutral density filters of different grades were fitted over the bottles for measuring photosynthesis at different light intensities. The revolving wheel was immersed in a large glass tank with running water so as to maintain a uniform temperature.

All experiments were carried out for 2 h on an open roof, between 11.30 and 13.30 hrs, on bright days, using solar radiation as the source of illumination. Before the experiment, and at regular intervals, the incident light falling on each chamber, with or without filters, was measured by a calibrated lux-meter (Dr. B. Lange's Type II) to calculate an average value. The incubator was placed at an angle to allow maximum exposure

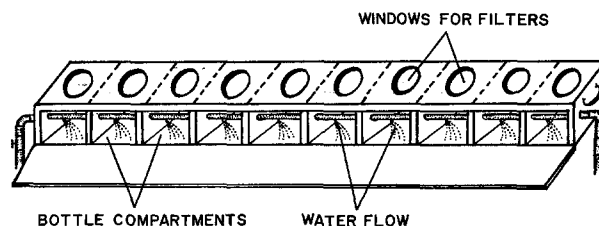


Fig. 1. A wooden incubator used for studying the photosynthetic rates of marine plankton algae under different quality of light. The incubator has 10 compartments to accommodate bottles. The circular windows on top are for fitting the sharp cut-type filters. A constant flow of water was maintained in all chambers

to sunlight. With each series, two dark bottles were taken and after the experiment the counts from the light bottles were corrected for the dark uptake.

For the measurement of photosynthesis under different quality of light, a special wooden incubator

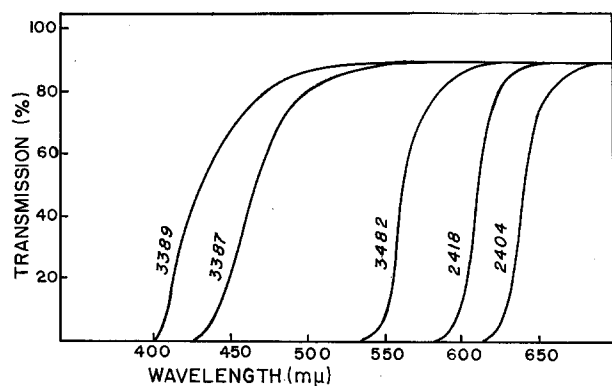


Fig. 2. Spectral transmission of the 5 Corning filters with their glass numbers. The filters are known as sharp cut-type. The percentage transmission of light of a portion of spectrum through each filter has been given from the wavelength known as the "cut"

was constructed. It also had 10 equal compartments to accommodate bottles, and each compartment had a circular window on top to allow the sharp cut-type filters of 63 mm diameter to be fitted in a light-tight fashion (Fig. 1). The colour filters were similar to those used by Beeton (1962) for the measurement of light penetration in Great Lakes, USA. These were supplied by the Corning Glass Works, Corning, New York, USA. The light transmittance characteristics of the five filters used and their numbers, as given by the suppliers (Corning Glass Works, 1965) have been shown in Fig. 2. The wavelength at which the transmittance was cut-off by each filter has been indicated in the figure. In other words, each filter transmitted only a portion of the spectrum, starting from the longest wavelength. No "heat glass" was used to remove wavelengths > 700 mμ.

Bottles of 50 ml capacity containing equal volumes of a particular organism with 1 ml ^{14}C bicarbonate were placed inside the incubator. With each series, 10 bottles in all, 5 with filters, 3 dark, and 2 without filters, were used. The bottles were kept cool by maintaining a constant circulation of water in each compartment. The experiments were conducted between 11.30 and 13.30 hrs, on sunny days with practically no

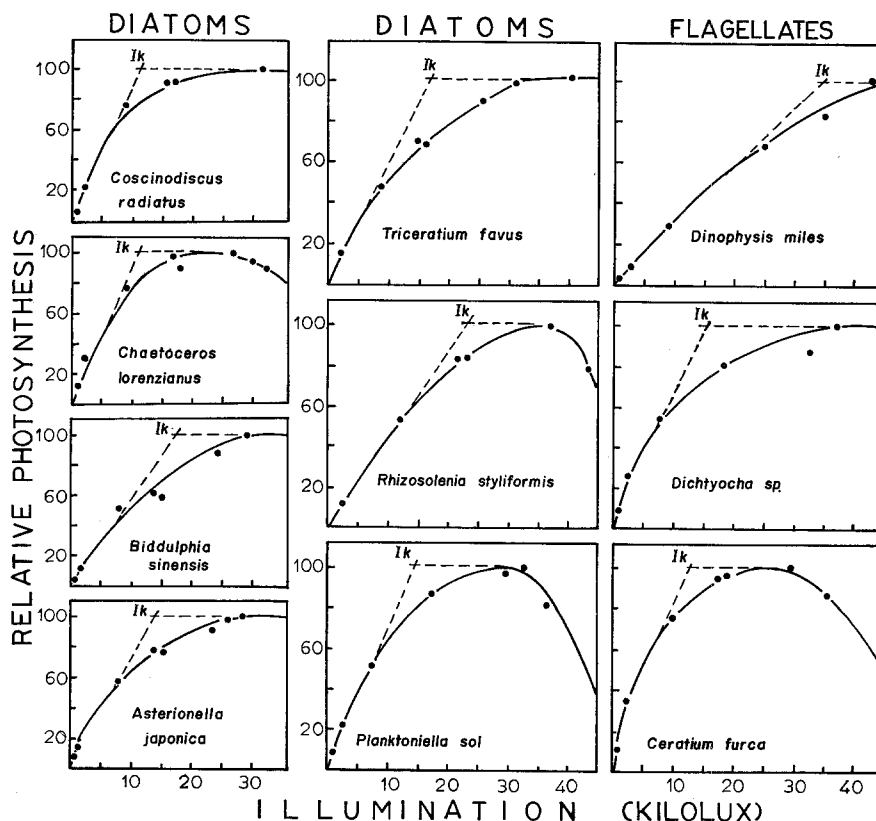


Fig. 3. Photosynthesis in different organisms as a function of light intensity. The intersection between linear and saturation regions of each curve, shown by broken lines, gives the saturation point (I_k)

Table 1. Saturation point (I_k) in different organisms, determined by the intersection of the linear and saturation regions of the curves (Fig. 3). The I_k values are characteristics of a photo-synthetic light response

Organisms	I_k (kilolux)	I_k (ly/min)
Diatoms		
<i>Asterionella japonica</i>	14.50	0.25
<i>Biddulphia sinensis</i>	17.75	0.31
<i>Chaetoceros lorenzianus</i>	11.75	0.21
<i>Coscinodiscus radiatus</i>	11.50	0.20
<i>Planktoniella sol</i>	14.50	0.25
<i>Rhizosolenia styliformis</i>	23.50	0.41
<i>Triceratium fавus</i>	17.25	0.30
Flagellates		
<i>Ceratium furca</i>	13.00	0.23
<i>Dichtyocha</i> sp.	15.50	0.27
<i>Dinophysis miles</i>	34.50	0.60

clouds, using sunlight as the source of illumination. The various experimental manipulations such as fitting the bottles, fixing the filters and regulating the flow of water were carried out indoors and then the incubator was exposed to solar radiation at an angle which provided no shade inside. All experiments were conducted in March and April, 1969.

Results

Intensity Effect

The relationship between photosynthesis and light intensity is shown in Fig. 3. At low intensities, the relationship between the two was linear. This was followed by a region of saturation, where with increasing light intensity, little or no further increase in photosynthesis occurred. Thereafter, in *Chaetoceros lorenzianus*, *Planktoniella sol*, *Rhizosolenia styliformis*

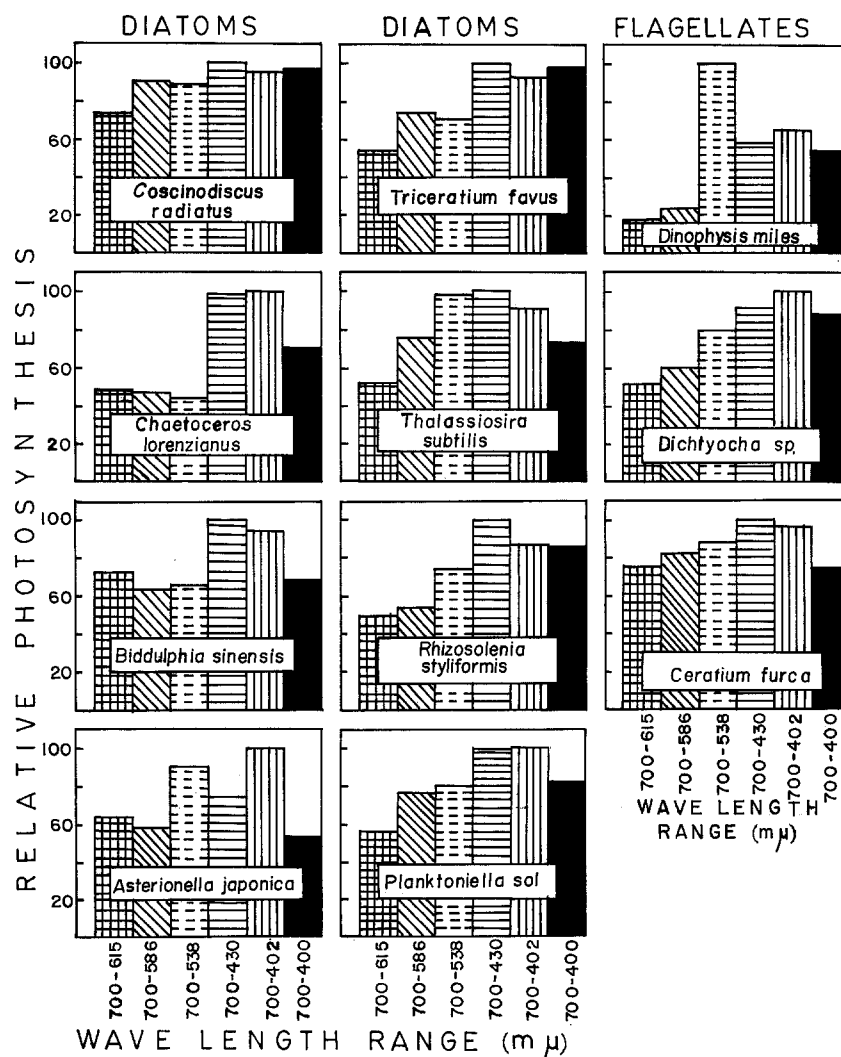


Fig. 4. Photosynthesis in different organisms in various portions of the visible spectrum and in the entire visible spectrum

and *Ceratium furca*, there was a progressive inhibition in photosynthesis as the light intensity increased. Almost similar curves between photosynthesis and light were obtained with natural phytoplankton populations (Qasim et al., 1969).

In some species, however, no significant inhibition took place within the range of illumination investigated. The points of intersection between the linear and saturation regions, denoted by I_k , which indicate the onset of light saturation, have also been shown in Fig. 3. Table 1 gives the values of I_k for different species. Among the diatoms, the highest I_k was found in *Rhizosolenia styliformis* (23 kilolux), but in the other species it ranged between 11 and 18 kilolux. The three species of flagellates showed wide variations in their I_k values (Table 1). In *Dinophysis miles*, the I_k was found to be unusually high (34 kilolux). *Dichtyocha* sp. (Silicoflagellate) had the I_k at about 15.5 kilolux.

Quality Effect

Fig. 4 shows the rate of photosynthesis in different organisms against the portion of the visible spectral band to which the organisms were exposed. The resulting photosynthesis in all the species was maximum in the spectral range 700 to 402 m μ and 700 to 430 m μ . *Dinophysis miles*, however, showed peak response between 700 and 538 m μ . Similarly, *Asterionella japonica*

and *Triceratium favus* showed secondary peaks in the wavelength range 700 to 538 m μ and 700 to 586 m μ , respectively. In most organisms, a sudden decrease in the rate of photosynthesis was noticed in the spectral range 700 to 586 m μ and 700 to 615 m μ . At these bands, photosynthesis was found to be 40 to 70% of the maximum. In *Coscinodiscus radiatus*, however, at these bands, the rate was about 80% of the maximum (Fig. 4). Probably the differences obtained in the

Table 2. Fractions of radiant energy in various wavebands as a percentage of total energy between 350 and 750 m μ determined from the table given by Strickland (1958). The difference between the energies transmitted by two sharp cut-type filters is given in Column 3, with filter numbers (Corning Glass Works, 1965) in Column 4

Region of waveband (m μ)	Energy (%)	Difference in the energy transmitted by 2 filters (%)	Filter numbers
400—430	5.19	6.40	3389—3387
430—540	31.34	30.90	3387—3482
540—590	14.98	16.00	3482—2418
590—620	8.88	9.00	2418—2404
620—700	23.12	19.40	2404

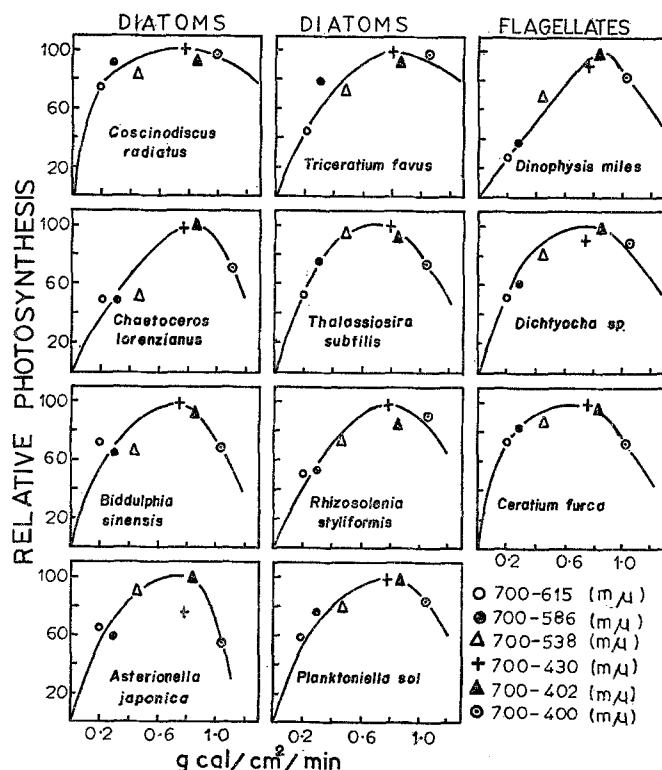


Fig. 5. Photosynthesis in different organisms as a function of total energy available in different wavelengths of the spectrum

photosynthesis of various species occurred because of the variation in the effectiveness of certain types of pigments in a particular spectral band.

The rate of photosynthesis in each organism for the entire visible spectrum (sunlight), 700 to 400 m μ , has also been given in Fig. 4. In most organisms, the photosynthetic rate was depressed at the high light intensity, probably because of photo-oxidation or some similar inhibitory processes. In *Coscinodiscus radiatus* and *Triceratium favus*, however, no such inhibitory effect was noticed.

These measurements indicate that almost all regions of the spectrum are effective for photosynthesis. Table 2 gives the difference in the energy transmitted by two filters. The values were calculated for the region of the various wavebands as a percentage of total energy in the spectrum of the sun, taking this to be slightly of a broader range than that of the visible (see Strickland, 1958, p. 458). The other method of calculation was the difference between the total energy transmitted by one filter and the other. Since one filter transmitted a greater part of the spectrum than the previous one, the difference in the percentage energy between the two gave the value for a narrow band as indicated in Table 2. As can be seen from Table 2, the energy values determined by the two methods agreed very closely.

In Fig. 5, relative photosynthesis has been plotted against the radiant energy transmitted through each filter. The rate of photosynthesis showed a linear function at low light energy, a saturation phase at higher energy, and an inhibition phase at still higher energy — a feature similar to that recorded in the light intensity curve (see Fig. 3). This shows that there is no wavelength dependence in saturating light.

Discussion

The photosynthetic response shown by the different marine phytoplankton as a function of light intensity was similar to those of other green plants (Rabinowitch, 1956). Several earlier authors have discussed the effect of illumination on the photosynthesis of phytoplankton (Ryther, 1956; Steemann Nielsen and Jensen, 1957; Kinne, 1970). The optimum light requirements for the different groups of phytoplankton have been determined by Ryther (1956). In *Chlorophyta*, the growth of the organisms increased linearly up to 0.03 ly/min, but in diatoms the optimum radiation was 0.07 ly/min. For dinoflagellates it was 0.16 ly/min. Strickland (1958) gives the range of optimum radiation for maximum photosynthesis in marine phytoplankton as 0.08 to 0.15 ly/min. For the different tropical organisms investigated during the present series of experiments, the optimum energy seems to range from 0.2 to 0.6 ly/min (see Table 1). This range is much greater than those reported for

the plankton algae from the temperate regions. Steemann Nielsen and Jensen (1957) give the I_k for the tropical natural phytoplankton as approximately 30 kilolux or 0.52 ly/min, which is fairly close to the I_k of some of the species given in Table 1.

Only in a few marine phytoplankton has the efficiency of utilization of light at various wavelengths been studied. In *Chlorella*, photosynthesis was found to be a linear function of intensity (Emerson and Lewis, 1943). Pickett and Myers (1966) found the light-saturated photosynthesis in *Chlorella* to be independent of the wavelengths between 450 and 705 m μ . In the marine diatom *Cylindrotheca closterium*, the compensation point in the rate of photosynthesis at blue light had the same energy as in white light (Humphrey and Subba Rao, 1967).

In most marine phytoplankton, the major pigments are carotenoids (polyoxy xanthophylls, fucoxanthin and peridinin) and chlorophylls (Haxo, 1960). The transfer of energy from the carotenoids to chlorophyll *a* varies from about 20% in the blue-green algae to 70–80% in brown algae (Govindjee, 1967). In phytoplankton organisms there does not seem to be much change in the pigment composition with depth, which indicates that a great deal of chromatic adaptation is possible within the euphotic zone. This has been clearly shown in lake plankton (Dutton and Judy, 1944), which is in contrast to littoral marine algae which grow at a particular depth in response to spectral quality of light to suit their pigmentation (Blinks, 1955). The study of quantum yield in two organisms, the green alga *Chlorella* (Emerson and Lewis, 1943) and the diatom *Navicula minima* (Tanada, 1951), as a function of wavelength, showed that, although the two organisms have different pigment composition, their behaviour is strikingly similar. The quantum yield was found to be practically constant in both the organisms from 550 to 680 m μ .

In the present series of experiments, the photosynthetic response shown by the different organisms in response to the variation in intensity and quality of light was in many ways quite similar. This provides evidence that marine plankton algae are capable of adapting themselves to changing light conditions fairly rapidly. Such behaviour would be of distinct advantage to these organisms, which have a floating existence. With the water current and wave action in the sea, they are rapidly subjected to changes in depth associated with a sudden change in the light conditions. The rate of photosynthesis, however, would not appear to be rapidly affected, even if a portion of the spectrum is cut off. The classical definition of "sun" and "shade" plankton would, therefore, have little ecological significance (see Yentsch and Lee, 1966). Under different light regimes, regulation of pigment content is a response fairly well known, and occurs in the form of balance between photo-oxidation and pigment synthesis.

Summary

1. Intensity effect in different phytoplankton organisms was determined by exposing them to varying intensities of sunlight for a period of 2 h. The saturation point (I_k) in most organisms was found to range between 11 and 15 kilolux. In *Rhizosolenia styliformis* and *Dinophysis miles*, the I_k values were exceptionally high.

2. When the organisms were exposed to a particular range of the visible spectrum by using sharp cut-type filters, no wavelength dependence of photosynthesis in saturating light was observed. All regions of the visible spectrum were found to be effective as long as there was enough light energy to stimulate photosynthesis.

3. Marked chromatic adaptation displayed by the organisms seems advantageous to marine phytoplankton because of their floating existence, which is normally associated with fairly rapid changes in depth and light conditions.

Acknowledgements. We are grateful to Dr. N. K. Panikkar for the encouragement we received from him during the course of this work, and to Dr. Govindjee, Professor of Botany and Biophysics, University of Illinois, USA, for his critical review and extremely helpful suggestions during the preparation of this manuscript.

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Date of final manuscript acceptance: May 31, 1972. Communicated by N. K. Panikkar, Panaji