Mahasagar–Bulletin of the National Institute of
Oceanography, *13* (2), 1980, 117–124

ADAPTATIONS IN PHYTOPLANKTON TO CHANGING CONDITIONS IN TROPICAL ESTUARIES

S. Z. QASIM
National Institute of Oceanography, Dona Paula–403 004, *Goa*

ABSTRACT

Experimental studies on phytoplankton organisms from Cochin backwaters (a tropical estuary) have shown that many algal forms are adapted to changing conditions of salinity, light and nutrients. Photosynthesis in 12 species of algae was found to be maximum in the salinity range 10 – 20°/₀₀. This feature is an adaptation to enable the organisms to utilize the enrichment of water for growth to a maximum degree during the monsoon months when large dilutions in the estuary occur. Reduction in light penetration due to high turbidity is another important factor in the estuary. Most of the organisms were found to have high values for light saturation intensity (I_k) and they appear to have no wavelength dependence in saturating light. Such a chromatic adaptation in the algae is to counteract the changing light conditions with depth to which they are exposed during their floatation. The green alga *Tetraselmis gracilis* was found to have a high requirement for phosphorus and this organism occurs in the estuary practically throughout the year but not in profusion. The diatom *Biddulphia sinensis* occurs very abundantly in the estuary when both phosphorus and nitrogen are maximum (monsoon months), while *Ceratium furca* forms blooms during the premonsoon season when these two nutrients are low. These deductions were made from the values of the half saturation constant (K_s) obtained for the three organisms.

INTRODUCTION

Environmental conditions in most of the tropical estuaries, found along the south–west coast of India, are largely governed by two main factors–short term changes resulting from the tides and marked seasonal changes induced by the monsoon cycle (Sankaranarayanan & Qasim, 1969). The tides influence several hydrographical features such as temperature, salinity, dissolved oxygen, pH, seston, nutrients, alkalinity and chlorophyll *a* and most of these have been studied by Qasim & Gopinathan (1969) with reference to Cochin backwaters. Marked changes in the hydrography of the estuaries occur during the monsoon months which affect the associated flora and fauna. The magnitude of variation in the estuaries depends upon the exact site of observation i.e. its proximity to the sea or the freshwater source. Heavy rainfall and land run–off affect the hydrography of the estuaries found along the south–west coast. Of the many changing conditions brought about by the monsoon in the estuaries, three appear to be of much importance governing the adaptations in phytoplankton organisms. These are: (1) salinity (2) light and (3) nutrients. Under each of these environmental conditions, optimum rate of photosynthesis was taken as an index of adaptation.

One of the best studied estuarine systems in India is the Cochin backwaters, and therefore, the adaptations described here would largely be related to this estuarine system.

Adaptations to changes in salinity

During the monsoon months (June–September), when large quantities of fresh-water enter the backwaters, salinity becomes very low at the surface and a clear stratification begins to exist in the water column with very low salinity at the surface and denser water near the bottom. The stratification gets broken during the postmonsoon months and salinity becomes homogenous throughout the water column. Large changes in the salinity, therefore, call for an adaptation in plant organisms not only to remain sufficiently euryhaline but to have their range of photosynthesis very nearly optimum at low salinities. To determine the adaptations in phytoplankton to changes in salinity, 12 organisms were isolated by species and cultured in the laboratory in enriched sea water. When the cultures became sufficiently dense, each organism was innoculated in bottles containing sea water of varying salinities. The bottles were exposed to constant light of 7 kilolux for a definite period and the rate of photosynthesis in each was studied by ^{14}C uptake (for details see Qasim, Bhattathiri & Devassy, 1972a). In this series of experiments it was possible to control most of the environmental factors while varying only the salinity. Fig. 1 shows the rates of photosynthesis in different organisms. The organisms showed wide adaptability to changes in salinity and in all the organisms maximum photosynthesis occurred at low salinities (10–20‰).

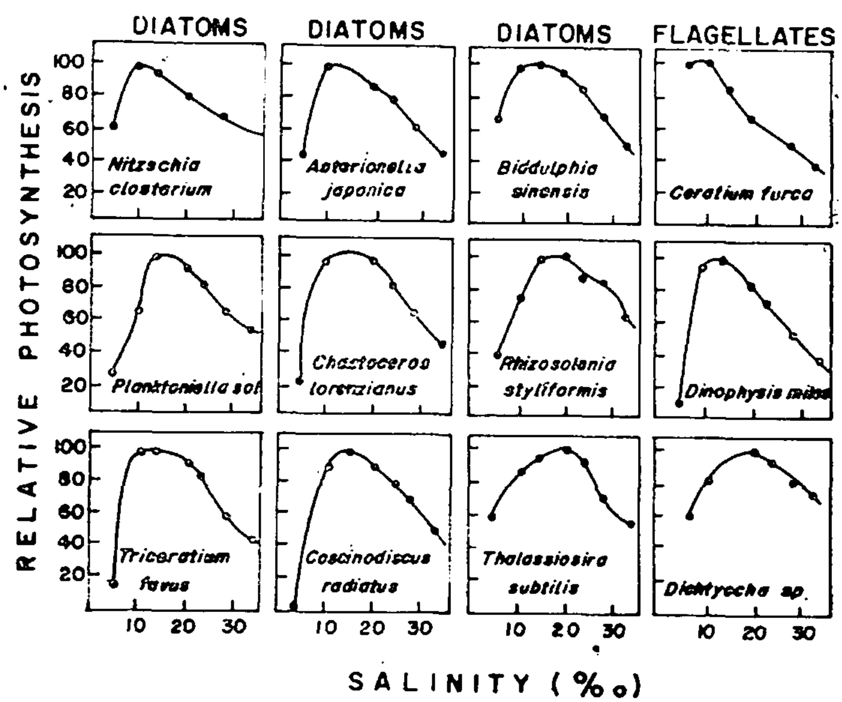

Fig. 1. Relative photosynthesis (rate as a percentage of maximum) shown by 12 organisms as a function of salinity.

These experiments clearly show that most of the tropical organisms are well adjusted to fairly large variations in salinity. The changes in the external environment are normally associated with rapid metabolic changes within the cell (Kinne, 1971), as the algal cell is osmotically labile to adjust itself quickly to outside changes. The tide pool flagellate *Monochrysis lutheri* has been shown to regulate its intracellular cyclitol (cyclohexanetetrol) content with the outside changes in salinity (Craigie, 1969). The rapid changes in cyclitol content is an adaptation in the organism to counteract rapid dilutions which the flagellate encounters in the rock pool.

In the coastal waters of India, reduction in salinity during the monsoon months is associated with enrichment of water with nutrients. A direct dependence of phytoplankton on high nutrient concentrations, therefore, must accompany their adaptability to low salinity. Thus the adjustment of photosynthetic maxima in phytoplankton organisms indicates a mechanism for regulating high production rates in neritic waters and estuaries.

Field data from Cochin backwaters clearly indicate that many organisms bloom successively at exceptionally low salinities. In the light of this, a much greater abundance of phytoplankton is likely to occur in nature when the salinity declines. Growth promoting effect of low salinity seems to be associated with the availability of humic acid brought into the environment with the land runoff. This is a biologically active substance and stimulates the growth and metabolism of dinoflagellates (Prakash & Rashid, 1968).

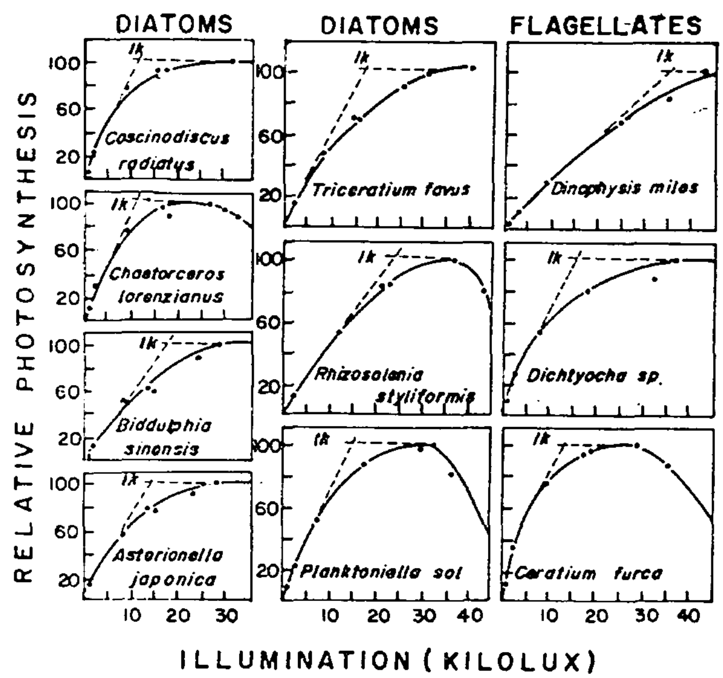

Fig. 2. Photosynthesis in 10 organisms as a function of light intensity. Points of intersection (I_k) indicate the onset of photosynthesis at light saturation.

Adaptation to changes in light

Maximum solar radiation (500–580 g cal cm^{-2} day^{-1}) reaches the backwater from January to April and minimum (250–300g cal cm^{-2} day^{-1}) in July and August (Qasim, Bhattathiri & Abidi, 1968). In the tropics, seasonal variation in total radiation is never a limiting factor for photosynthesis. The high turbidity prevailing in the estuary, on the other hand, reduces the light penetration considerably. During the monsoon months because of the opacity of water, the underwater illumination gets reduced to about 20% of the incident radiation within 1 m and 1% at 3 m (Qasim, Bhattathiri & Abidi, 1968). With such a limitation in the light penetration, despite the adaptations in increasing the photosynthetic efficiency under subdued light, primary production in the backwaters becomes non-existent at depths greater than 6 m. The euphotic zone varies from 2 to 6 m during the year with the attenuation coefficient (k) ranging from 0·60 to 3·00 (Qasim, Bhattathiri & Abidi, 1968). Within the euphotic zone, the phytoplankton organisms occurring at different depths are exposed to different intensity and quality of light (Kinne, 1970).

The adaptation of different phytoplankton organisms to the intensity and spectral characteristics of light was studied by conducting laboratory experiments on unialgal cultures. Ten species of diatoms and flagellates were taken and equal

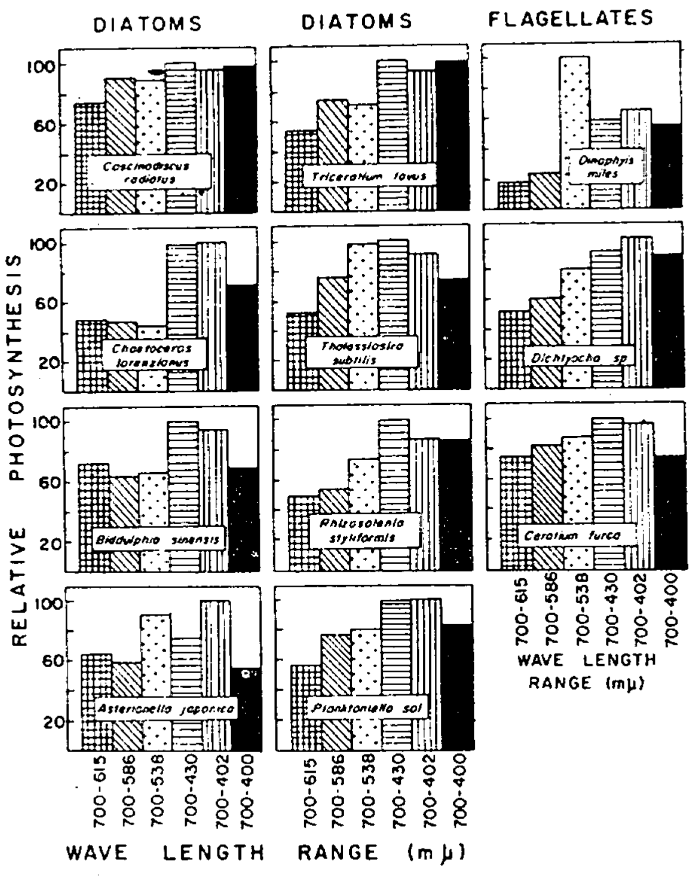

Fig. 3. Photosynthesis in phytoplankton organisms in relation to different regions of the spectrum.

quantities of each were innoculated in separate bottles containing Millipore-filtered sea water. The bottles were clamped in an incubator provided with graded neutral density filters. The incubator was exposed to sunlight and the rate of photosynthesis in each bottle was measured by ^{14}C uptake. The incident light falling on each bottle was measured by a calibrated lux-meter and the results were expressed as the intensity effect of light. The duration of each experiment was 2 hours (for details see Qasim, Bhattathiri & Devassy, 1972b).

Fig. 2 shows the relationship between photosynthesis and light. The relationship between the two at low intensities was linear. This was followed by a region of saturation, where with increasing light intensity, little or no further increase in photosynthesis occurred. Thereafter, there was a progressive inhibition in photosynthesis as the light intensity increased. The points of intersection between the linear and saturation regions, have been shown by I_k in different species. The I_k in most of the organisms ranged between 11 and 18 kilolux. This range is much greater than that for the plankton algae from the temperate region.

In addition to the intensity effect, the quality effect of light was also investigated. Bottles containing each organism were exposed to a portion of the visible spectrum, starting from the longest wavelength. Sharp cut-type glass filters were used in a specially designed incubator for cutting off the transmittance of light (see Qasim, Bhattathiri & Devassy, 1972 b).

The rate of photosynthesis in different organisms against a portion of the visible spectral band to which the organisms were exposed, is shown in Fig. 3.

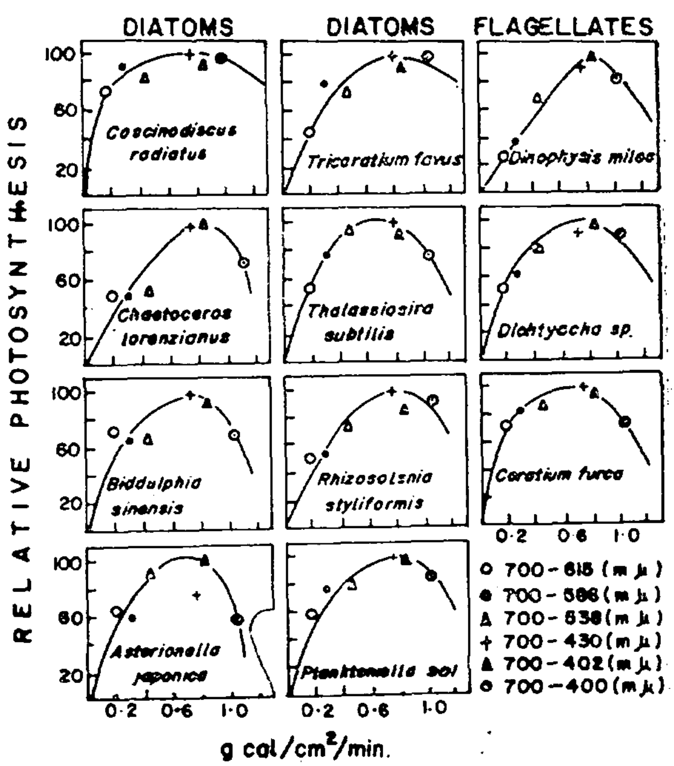

Fig. 4. Photosynthesis in phytoplankton organisms as a function of total energy in different wavelengths.

Maximum photosynthesis was obtained in the spectral range 700–402 mμ and 700 to 430 mμ. In most organisms, at the high light intensity, probably because of photo-oxidation or due to some similar inhibitory processes, the photosynthetic rate was depressed. From these measurements it is clear that almost all regions of the spectrum are effective for photosynthesis. Fig. 4 shows the relative photosynthesis plotted against the radiant energy transmitted through each filter. The rate of photosynthesis obtained was found to be similar to that recorded in the light intensity curve (see Fig. 2). This feature indicates that there is no wavelength dependence in saturation light.

The major pigments in most marine phytoplankton organisms are carotenoids and chlorophylls. The transfer of energy from carotenoid to chlorophyll *a* varies from about 20% in the blue-green algae to 70–80% in the brown algae (Goovindjee, 1967). Pigment composition in phytoplankton algae does not change much with the depth which indicates that, within the euphotic zone, a great deal of chromatic adaptation is possible. Photosynthetic response shown by the different organisms in response to quality of light indicates that phytoplankton can adapt themselves to changing conditions of light fairly rapidly. Such a chromatic adaptation is of distinct advantage to phytoplankton organisms which have a floating existence. With water currents and wave action they are subjected to rapid changes in depth, but their photosynthesis would not be affected much, even when a portion of the spectrum of light to which they are exposed, is cut off.

Adaptations to changes in nutrients

Effects of nutrients on algal growth have been demonstrated by several authors (see Goldman & Carpenter, 1974) to follow the Monad model which states:

$$\mu = \mu_{max}\left(\frac{S}{K_s + S}\right)$$

Where μ is the specific growth of the algae, μ_{max} is the maximum growth rate unlimited by low nutrient concentration, S is the nutrient concentration and K_s is the half saturation constant which is equal to $\mu_{max}/2$.

Nutrient-depleted cells of three organisms–a diatom *Biddulphia sinensis*, a flagellate *Ceratium furca* and a green alga *Tetraselmis gracilis*, were allowed to grow in Millipore-filtered sea water containing varying concentrations of nitrate, phosphate either singly or in combination (Qasim, Bhattathiri & Devassy, 1973; Qasim & Joseph, 1975). Small quantities of cellular material were pipetted out from each flask at regular intervals and these were incubated for 3 hours under constant illumination and their rates of photosynthesis were measured by ^{14}C uptake. Values of saturation constant K_s and maximum growth rate μ_{max} were determined graphically by plotting the values of specific growth rate (μ) against μ/s and fitting the straight line statistically. Fig. 5 shows these plots and Table I gives the values of K_s and μ_{max} for the three algal species.

All the three organisms are of common occurrence in Cochin backwaters where nutrients occur in fairly high concentrations. *Tetraselmis* has a very high K_s for phosphate when this nutrient was used either singly or in combination. Probably for this reason, this organism is found throughout the year in the estuarine system. It is

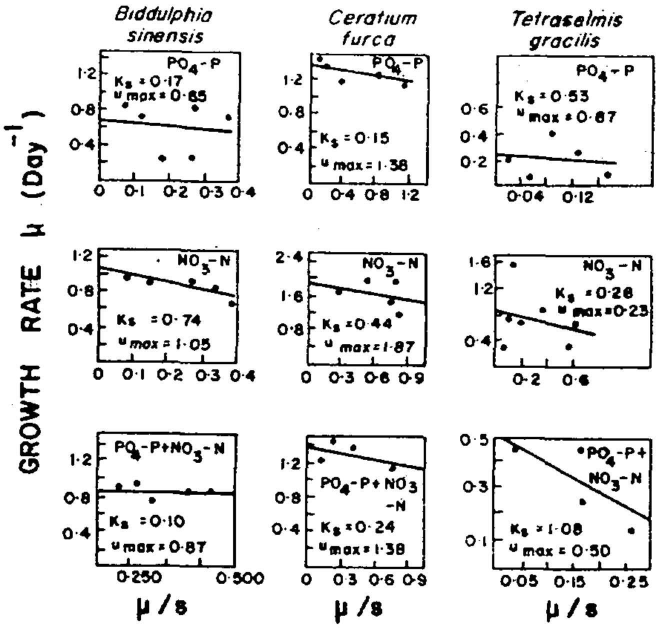

Fig. 5. Plot of growth rate (μ) against the ratio between growth rate and nutrient concentration μ/S to determine the values of half saturation constant K_s and maximum growth rate (μ_{max})

a common green alga but has not been reported to form blooms. *Biddulphia* also has a high K_s for both phosphate and nitrate and in the backwaters it becomes abundant during the monsoon months when both phosphate and nitrate are maximum. *Ceratium*, on the other hand, has a low K_s and hence it is a better competitor at low concentrations of nutrients than either *Tetraselmis* or *Biddulphia*. Therefore, in the backwaters, *Ceratium* occurs in large concentrations during the premonsoon months (March–April) when the nutrients are low. Each organism, thus, seems to be adapted to a particular level of nutrients and the maximum growth and observed succession of different organisms can be explained from their growth kinetics.

Table I. Values of half saturation constant (K_s) and maximum growth rate (μ_{max}) obtained for three phytoplankton organisms

	Biddulphia sinensis			*Ceratium furca*			*Tetraselmis gracilis*		
	Phosphate	*Nitrate*	*Phosphate + Nitrate*	*Phosphate*	*Nitrate*	*Phosphate + Nitrate*	*Phosphate*	*Nitrate*	*Phosphate + Nitrate*
K_s	0·17	0·74	0·10	0·15	0·44	0·24	0·53	0·28	1·08
μ_{max}	0·65	1·05	0·87	1·38	1·87	1·38	0·87	0·23	0·50

From these studies it is clear that the continued existence and propagation of phytoplankton organisms in estuaries call for adaptations to changing conditions and the ways in which these have been achieved among the phytoplankton is a fascinating field of study.

REFERENCES

Craigie, J. S., 1969. Some salinity-induced changes in growth, pigments and cyclohexanetetrol content of *Monochrysis lutheri*. *Journal of Fisheries Research Board of Canada*, **26**: 2959-2967.

Goldman, J. C. and E. J. Carpenter, 1974. A kinetic approach to the effect of temperature on algal growth. *Limnology & Oceanography*, **19**: 756 - 766.

Goovindjee, 1967. Transformation of light energy into chemical energy: photochemical aspects of photosynthesis. *Crop Science*, **7**: 551 - 560.

Kinne, O. (Ed.) 1970. *Marine ecology*, Vol. 1. Environmental factors, part 1, pp. 1-681. London: Wiley - Interscience.

Kinne, O. (Ed.) 1971. *Marine ecology*, Vol. 1. Environmental factors, part 2, pp. 683-1244. London : Wiley - Interscience.

Prakash, A. and M. A. Rashid, 1968. Influence of humic substances on the growth of marine phytoplankton: dinoflagellates. *Limnology & Oceanography*, **13**: 598-606.

Qasim, S. Z., P. M. A. Bhattathiri and S. A. H. Abidi, 1968. Solar radiation and its penetration in a tropical estuary. *Journal of Experimental Marine Biology and Ecology*, **2**: 87 - 103.

Qasim, S. Z., P. M. A. Bhattathiri and V. P. Devassy, 1972 a. The influence of salinity on the rate of photosynthesis and abundance of some tropical phytoplankton. *Marine Biology*, **12**: 200 - 206.

Qasim, S. Z., P. M A. Bhattathiri and V. P. Devassy, 1972 b. The effect of intensity and quality of illumination on the photosynthesis of some tropical marine phytoplankton. *Marine Biology*, **16**: 22 - 27.

Qasim, S. Z., P. M. A. Bhattathiri and V. P. Devassy, 1973. Growth kinetics and nutrient requirements of two tropical marine phytoplankters. *Marine Biology*, **21**: 299 - 304.

Qasim, S. Z., and C. K. Gopinathan, 1969. Tidal cycle and the environmental features of Cochin Backwater (a tropical estuary). *Proceedings of the Indian Academy of Sciences*, **59 B**: 336 - 346.

Qasim, S. Z. and K. J. Joseph, 1975. Utilization of nitrate and phosphate by the green alga *Tetraselmis gracilis* Kylin. *Indian Journal of Marine Sciences*, **4**: 161 - 164.

Sankaranarayanan, V. N. and S. Z. Qasim, 1969. Nutrients of the Cochin Backwater in relation to environmental characteristics. *Marine Biology*, **2**: 236 - 247.