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Influence of Hydrological Factors on the Seasonal Abundance of Phytoplankton in Kinjhar Lake, Pakistan

key words: reservoir, tropic, phytoplankton abundance, light, temperature

Abstract

The correlation of various hydrological factors with the distribution of phytoplankton and bacteria has been studied in Kinjhar Lake, situated 120 km north of Karachi. This lake is highly eutrophic, containing rich concentrations of nutrients, but the temporal distribution of phytoplankton was generally related to the variations of light and temperature. The effects of light and temperature are perhaps modified by nutrients, particularly when nitrogen and phosphorus are present in surprisingly low concentrations. The effect of mechanical disturbances in the artificial lake also has a significant effect on the growth of phytoplankton and indirectly on consumers, especially fishes.

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1. Introduction

Kinjhar Lake is situated 120 km north of Karachi in Pakistan, at 24°47'N and 68°2'E (Blatter et al. 1929). Its area is 80 km². This artificial lake is supplied by a canal, “Kalri Baghar Feeder,” from the River Indus, and the water from the lake is pumped to Karachi, a city of four million people, for daily use. It is thus important as the only source of water created artificially to supply this large city. This study
was undertaken not only to determine the quality of the water, but also to develop this lake for fishing.

The phytoplanktonic species in the lake, which serve as food for fishes, were studied to correlate their abundance with various physical and chemical factors. Such work has not been done earlier in Pakistan, and this is perhaps the first such study in this region.

Species composition and distribution of phytoplankton in any environment depend generally upon intensity of light, duration of illumination, temperature, concentration of nutrients and pH. In tropical regions, the water temperature remains high and uniform throughout most of the year, and day length is also uniform. Vertical sunlight provides maximum penetration of light into the water. High temperatures and strong radiations are thus the principal factors in the tropical areas which are responsible for the abundance of phytoplankton (Fish 1956). It is also obvious that the phytoplankton of tropical lakes tolerates high temperatures (Ricker 1937, Lund 1949, Spencer 1950, McCombie 1953, George 1962). Climatic conditions in tropical lakes are therefore unlikely to impose limits on production (Fish 1956), in contrast to temperate lakes where low temperature and light in winter are frequently limiting factors (Ruttner 1963).

In addition to temperature and light, chemical factors also play an important role in determining the pattern of distribution and abundance of phytoplankton (Singh 1960, Rodhe 1964, Fogg 1965, Javornicky 1966, Megard 1972, Gorham et al. 1974). The importance of various physical and chemical factors for phytoplankton growth has been thoroughly investigated in the temperate regions, but comparatively little information is available on this aspect in tropical waters.

This paper describes physical and chemical factors and their correlation with the distribution pattern of various phytoplankton species, the survey of which appeared in an earlier publication (Nazneen 1974).

2. Material and Methods

The weather data were obtained from the Pakistan Meteorological Department at Karachi. The temperature of the water at various depths was measured directly in the field, and data for surface temperature were obtained from Bada et al. (1974).

Chemical factors were measured from April 1970 to March 1971. The water samples were collected from a rowboat, mostly fortnightly, using Nansen sampling bottles at 0.3 m intervals through the water column from the surface to a depth of 3 m. Sampling was usually carried out between noon and 3 P.M. at the Boat Club, the deepest area of Kinjhar Lake. The water was then stored in a deep freeze in plastic bottles of a half liter capacity, and the chemical analyses were made within 24 hours. The pH, however, was measured by the lake side using pH paper. All samples were filtered before analysis, and their optical densities were recorded in a spectrophotometer.

Dissolved oxygen was measured by the Winkler procedure (Welch 1952). Free carbon dioxide was titrated against 1/44 N sodium hydroxide solution with phenolphthalein as the indicator (Ellis et al. 1948). The inorganic phosphate was estimated with ammonium molybdate and ascorbic acid (Fogg & Wilkinson 1958). The amount of ammonia was determined by the modification of Ellis et al. (1948) of the Nessler method. Nitrite-nitrogen was estimated using Greiss Illosway reagent, while nitrate-nitrogen was determined using phenoldisulfonic acid (Snell & Snell 1949). The amount of silica was measured by the method recommended by the Institute of Water Engineers, London (1953). Total iron was determined with a potassium thiocyanate solution, while manganese content was measured with sodium periodate, following the methods of Ellis et al. (1948).
3. Climatic Conditions

A gradual rise in the average atmospheric temperature was observed from February to June, followed by a decrease in July, while the lowest temperature occurred in January (Fig. 1).

The climate of Sind, the area in which the lake is situated, is very dry. The lowest annual rainfall was observed in 1968, while the heaviest annual rainfall was recorded during 1970. The greatest proportion of the rainfall occurred during the summer months (Fig. 1).

The time of exposure to bright sunshine increased from March to May. Sunshine hours decreased from June to August (Fig. 1) due to the presence of clouds (cloud cover from June to August varies between 3.6 and 6.0 oktas), as shown in Table 1.

4. Water Temperature

The annual low temperature range was recorded in January, and the highest in May and July, 1969. The water temperature (Fig. 2) followed the same trend as that observed for atmospheric temperature (Fig. 1). A similar direct relationship between
Table 1. Mean cloud cover (oktas)* from March 1968 to February 1971

| months | 5 A.M. 1968 | 8 A.M. 1968 | 5 P.M. 1968 | 5 A.M. 1969 | 8 A.M. 1969 | 5 P.M. 1969 | 5 A.M. 1970-71 | 8 A.M. 1970-71 | 5 P.M. 1970-71 |
|--------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
| March  | 0.4        | 1.2        | 0.5        | 1.3        | 1.9        | 2.0        | 1.6        | 1.9        | 1.6        |
| April  | 1.4        | 2.4        | 2.1        | 0.6        | 1.7        | 1.2        | 1.2        | 2.1        | 1.7        |
| May    | 2.3        | 2.8        | 1.0        | 2.4        | 2.6        | 0.8        | 2.8        | 3.8        | 1.2        |
| June   | 3.7        | 5.1        | 2.7        | 4.2        | 4.2        | 2.3        | 3.3        | 4.5        | 6.3        |
| July   | 4.9        | 5.5        | 4.3        | 5.4        | 5.6        | 4.9        | 5.3        | 6.2        | 5.3        |
| August | 6.9        | 6.7        | 5.6        | 6.4        | 6.4        | 5.2        | 6.0        | 6.5        | 5.8        |
| Sept.  | 3.0        | 3.3        | 3.1        | 3.0        | 4.4        | 2.8        | 4.3        | 5.1        | 4.8        |
| Oct.   | 0.4        | 0.5        | 0.4        | 1.5        | 1.4        | 0.7        | 0.9        | 1.1        | 0.7        |
| Nov.   | 0.5        | 1.4        | 1.7        | 1.7        | 1.3        | 1.8        | 0.2        | 0.1        | 0.3        |
| Dec.   | 0.4        | 1.0        | 1.2        | 1.0        | 2.0        | 1.7        | 0.6        | 0.9        | 1.3        |
| Jan.   | 0.1        | 0.2        | 0.1        | 0.7        | 1.9        | 1.8        | 1.1        | 1.4        | 1.4        |
| Feb.   | 0.4        | 0.4        | 0.5        | 1.1        | 1.3        | 1.4        | 0.3        | 0.8        | 0.7        |

* Okta is the unit for measurement of cloud cover. When 1/8 of the sky is covered, this is equivalent to one okta.

Figure 2. Variations in the monthly mean values of water temperature from March 1968 to February 1971.

Water and atmospheric temperature has also been noted by Ganapati (1940) and Jayangoudar (1964).

The temperature at various depths (0.3–3 m) was measured from March 1970 to February 1971. Only during the period of December and January was there a difference of about 2 °C between the surface water temperature and that at 3 m (18.6–20.6 °C), the surface water being colder than the deep water. No remarkable difference in the temperature of the surface and at various depths was noticed after January. The variations of temperature at different depths were irregular, with only minor fluctuations. They did not follow any pattern.

5. Chemical Factors

Observations regarding the chemical composition of the different water masses show that nutrient level plays an important role regulating the growth and distribution of phytoplankton species.
a. pH

The pH value generally varied from 6.9 to 7.5, but the maximum of 8.0 was noted each year in June and July (Fig. 3). No marked difference was observed between the surface and various depths.

There is a considerable difference of opinion regarding the effect of pH on phytoplankton abundance. Some researchers (Gerloff et al. 1952, George 1962) have suggested that high pH values promote the growth of phytoplankton and result in "blooms." On the other hand, McCombie (1953) and Prescott & Vinyard (1965) argued that high values during blooming periods are the result and not the cause of phytoplankton blooms. The latter explanation seems to be more convincing in Kinjhar Lake.

b. Dissolved oxygen

Irregular fluctuations in the dissolved oxygen of the water occurred, and the monthly mean oxygen concentration varied from 2.25 to 7.31 mg/l at the surface (Fig. 3), and from 1.8 to 6.26 mg/l below. Relatively high values of oxygen in the surface water occurred each year in January and July. The general increase in oxygen content during July occurred because of a phytoplankton bloom (Ganapati 1940), while the increase during winter has been attributed by Minder (Hutchinson 1967) to physical aeration rather than biological events, a hypothesis that seems to be more convincing. The differences in oxygen value could be due to one or more factors, such as temperature, light intensity, photosynthetic processes and respiration.

c. Free carbon dioxide

The carbon dioxide concentration fluctuated between 2.0 and 7.5 mg/l. It usually remained nearly constant at different depths, but irregular fluctuations were noticed below the surface during June and December. Sreenivasan (1965) also found similar irregularities in carbon dioxide content between surface and deep water in a Madras reservoir.
d. Inorganic phosphate

The concentration of inorganic phosphate fluctuated between 5 and 1300 µg/l (mean monthly value in the whole water column, 700 µg/l). The minimum concentration was recorded in November and the maximum in October (Fig. 4). A significant amount of inorganic phosphate was found throughout the year, except during November 1970 (Fig. 4). The level varies from time to time, and it is interesting to note that these fluctuations, to significant degrees, do not seem to affect the distribution of phytoplankton species, particularly Microcystis aeruginosa. However, when the phosphate content falls below the minimum required for phytoplankton production, growth is seriously limited. The maximum abundance of *M. aeruginosa* is associated with a surprisingly low concentration of phosphate (Gerloff et al. 1952), so a considerable amount of inorganic phosphate is left after luxuriant growth of this species (George 1962).

The excess amount of inorganic phosphate in October at various depths seems to be due to the decomposition of zooplankton (Harvey 1960), the maximum rainfall (Duthie 1968) which occurred in August and September 1970 (Fig. 1), or a combination of both of these factors. The sudden fall in inorganic phosphate in November is also quite interesting and may be due to the rapid initial liberation of phosphate from

![Figure 4](image-url)  
*Figure 4.* Seasonal changes in the concentration of inorganic phosphate, ammonia, nitrite, nitrate and silica in the whole water column (mean monthly values from surface to 3 m) from April 1970 to March 1971.
organic detritus in October, which slowed suddenly in November, when a marked decrease in the detritus particle size occurred (SEIWELL & SEIWELL 1938); to the activity of phosphate utilizing bacteria, such as *Achromobacter guttatus*, which were present as a high percentage of total bacteria (NAZNEEN & SIDDIQUI 1976) during this period; to high mixing of low phosphate water from the inlet, which diluted the phosphate concentration of the water at the sampling spot; or to a combination of all these factors.

e. Ammonia, nitrite and nitrate

The concentration of ammonia varied very irregularly at different depths, and no definite pattern could be detected (Fig. 4). It may be assumed that these irregularities both at the surface and at various depths could arise from the uneven distribution of animal wastes or the decomposition of phytoplankton, submerged weeds and zooplankton through bacterial activity without the formation of intermediate products (HUTCHINSON 1957).

Nitrite was present in very small amounts, usually between 1 and 8 µg/l (Fig. 4). The general pattern of nitrite distribution is similar to those of ammonia and nitrate, except in winter. No effect of variations in the nitrite level on phytoplankton abundance was observed.

As in the case of ammonia, the nitrate concentration was also variable, 70–200 µg/l, and no obvious pattern could be observed (Fig. 4). Nitrate was always present in significant amounts, except in May and December. The results show that during May, nitrate reducing bacteria, e.g. *Alcaligenes faecalis*, *Micrococcus roseus* and *Escherichia coli*, were present in large numbers (NAZNEEN & SIDDIQUI 1976). Also in December, rich concentrations of *Micrococcus denitrificans* and *E. coli* were observed. It may also be seen that the nitrate level is lower in May than in December (NAZNEEN & SIDDIQUI 1976). Thus, it seems safe to suggest that the nitrate level is controlled by the bacterial activities and by nitrogen-fixing Cyanophyta, and the irregularities recorded throughout the year may also be attributed to variations induced by these factors.

The maximum concentration of nitrate was found in June, which was also the blooming period of phytoplankton species, especially *Microcystis aeruginosa* (NAZNEEN 1974). This shows that, in spite of the nitrate being continuously used up by the algae, there was still an excess amount left in the water. This may be due to the regeneration of nitrate in water by bacterial species, such as *Achromobacter* spp. and *Azobacter* sp., considerable concentrations of which were observed during this period (NAZNEEN & SIDDIQUI 1976) and by nitrogen-fixing Cyanophyta. It has been found that Kinjhar Lake is similar in some respects to Roshanara Tank, where GEORGE (1962) observed the continuous presence of nitrate in considerable amounts. GANAPATI (1940), during his investigations on a fish tank at Delhi, which contained a permanent bloom of *Microcystis aeruginosa*, noticed that ammonical nitrogen is a limiting factor for the species in the absence of nitrate. This does not seem to be the case in Kinjhar Lake, as both nitrate and ammonia-nitrogen concentrations were low at the surface in December. The overall abundance of the phytoplankton was, however, lower in May than in December, although the level of ammonical nitrogen was high in May compared to December.

f. Silica

The concentration of silica usually remained relatively high throughout the whole water column (Fig. 4). Insoluble silicates are the chief components of the soil of the Indus Delta (BLATTER et al. 1929). The soluble form of the silica circulates freely
in the soil water, resulting in an increase of the silica level in the river water. River waters are relatively rich in silica and often markedly affect the silica concentration of those lakes which originate from them (Welch 1952), thus the high concentration of silica in Kinjhar Lake seems to be due to its origin. However, quantities may vary with the season, nature and periodicity of inflowing water, depth and other factors.

The curve representing diatom abundance in Kinjhar Lake followed the curve of silica concentration (Fig. 4), the first peak occurring in June and the second in October (Nazneen 1974). The maximum concentrations of silica were also observed in these two months. Singh (1964) also recorded two peaks of silica concentration, occurring in June and August. A large diatom population was found throughout the year due to the presence of substantial amounts of silica. It has also been noted by Hutchinson (1957) that waters in the tropics have more silica than those in temperate regions.

**g. Total iron and manganese**

Total iron and manganese concentrations were recorded from March 1970 to January 1971, usually trimonthly. In Kinjhar Lake, the level of total iron usually did not rise above 1 mg/l. It has been reported that the iron concentration in water is controlled by pH values, and that it never rises above 1 ppm in alkaline waters, pH 7.2–8.6 (Vankateswarlu 1969). The results of this study also suggest that the iron concentration is very sensitive to pH, which usually remained within the alkaline range. Besides pH, bacterial activities may also affect the iron concentration (Smith et al. 1957, Lamanza et al. 1973) and may account for some irregularities observed during the period of study.

A significant amount of manganese was found in Kinjhar Lake. This lake consists chiefly of river water, and it is known that such waters contain relatively large quantities of manganese (Twenhofel 1938). Harvey (1949) has suggested that manganese content does not affect the productivity. Moreover, no direct effect of manganese on growth of phytoplankton was observed in Kinjhar Lake.

6. **Seasonal Grouping of Phytoplankton Based on the Interaction of Light and Temperature**

In addition to temperature, the duration of sunshine periods (Rice 1938, Singh 1964, Stepanek 1959) and the intensity of the light (McCombie 1953) have also been reported to be among the most important factors controlling the occurrence and abundance of phytoplankton species.

Rutten (1930) discussed the interaction of light and temperature relative to individual species, but the relationship of the annual phytoplankton cycle to the interaction of these factors has been clarified primarily by Findeneg (1943). He pointed out that if the light and temperature requirements vary independently, then it is possible to obtain the following four groups of organisms:

1. Low temperature and low light species of winter,
2. Low temperature and high light species of spring,
3. High temperature and high light species of summer,
4. High temperature and low light species of autumn.

These four groups are inadequate for the description of seasonal distribution of individual species in the tropical environment due to gradual changes in the interaction of light and temperature. Based on our observations made at Kinjhar Lake, it
seems more convenient and informative to describe the distribution of tropical phytoplankton species in terms of the ten groups described below.

Maxima of population densities are generally observed at the same time of year. The following are the average maximum counts of various species observed from March 1968 to February 1971 at the surface, and the maximum counts of various species in deeper layers of the water column observed from March 1970 to February 1971:

Group I. Species observed only during spring:
- *Anomoeneis axilis* (15 x 10^2 cells/l), *Gyrosigma attenuatum* (23 x 10^2 cells/l), *G. scaploides* (23 x 10^2 cells/l), *Navicula cryptocephala* (16 x 10^2 cells/l), *N. seminulum* (33 x 10^2 cells/l), *Nitzschia hungarica* (4 x 10^2 cells/l), *Cosmarium aaprospeciosum* (2 x 10^3 cells/l), *Desmid sp.* (4 x 10^2 cells/l), *Mougeotia thyllopsora* (3 x 10^3 cells/l).

Species occurring only below the surface
- *Anabaena variabilis* (27 x 10^3 cells/l), *Anabacenosps elenkii* (176 x 10^5 cells/l), *A. milleri* (237 x 10^4 cells/l), *Asterionella formosa* (1 x 10^3 cells/l), *Caloneis bacillum* (5 x 10^3 cells/l), *Diploneis oralis* (2 x 10^2 cells/l), *Spirogyra neglecta* (19 x 10^3 cells/l), *S. subreticulata* (23 x 10^3 cells/l), *Stigonema ocellatum* (214 x 10^3 cells/l).

Group II. Species observed during spring and summer:
- *Fragilaria construens* (21 x 10^2 cells/l), *Neidium productum* (11 x 10^2 cells/l), *Nitzschia sigmoidea* (11 x 10^2 cells/l), *Pinnularia major* (144 x 10^2 cells/l), *Surella splendida* (10 x 10^2 cells/l), *Chlorhormidium flaccidum* (171 x 10^3 cells/l), *Cosmarium fontigenum* (64 x 10^6 cells/l), *Pediasstrum* sp. (64 x 10^6 cells/l), *P. simplex* (20 x 10^6 cells/l), *Spirogyra sphaerocarpa* (962 x 10^3 cells/l).

Group III. Species observed only during summer:
- *Anabaena sp.* (94 x 10^3 cells/l), *Gomphosphaeria noegelianana* (26 x 10^5 cells/l), *Merismopedia glauca* (23 x 10^3 cells/l), *M. tenusima* (57 x 10^5 cells/l), *Nostoc sp.* (5 x 10^2 cells/l), *Phormidium boryanum* (96 x 10^2 cells/l), *Cymatopleura elliptica* (7 x 10^2 cells/l), *C. solea* (4 x 10^2 cells/l), *Cyclotella compta* (16 x 10^5 cells/l), *Syneclera acus* (11 x 10^2 cells/l), *Scenedesmus quadricauda* (326 x 10^2 cells/l).

Species occurring only below the surface
- *Cosmarium cucurbita* (6 x 10^3 cells/l).

Group IV. Species observed irregularly during various seasons with maxima generally in summer:
- *Lynphyba birgei* (4951 x 10^3 cells/l), *Microcystis aeruginosa* (2776 x 10^6 cells/l), *Achnanthes hungarica* (152 x 10^2 cells/l), *Cocconeis placentula* (145 x 10^2 cells/l), *Cymbella cymbiformis* (320 x 10^5 cells/l), *C. tumida* (375 x 10^3 cells/l), *C. ventricosa* (79 x 10^5 cells/l), *Diatoma vulgare* (161 x 10^2 cells/l), *Epithemia argus* (32 x 10^6 cells/l), *Fragilaria eirensens* (162 x 10^4 cells/l), *Gomphonieis sp.* (8 x 10^2 cells/l), *Melosira granulata* (139 x 10^3 cells/l), *Navicula radiosa* (11 x 10^3 cells/l), *Pinnularia viridis* (1 x 10^6 cells/l), *Rhodolodia gibba* (313 x 10^3 cells/l), *Syneclera ulna* (3 x 10^6 cells/l), *Spirogyra fuellobornei* (35 x 10^5 cells/l), *S. hollandiae* (15 x 10^7 cells/l), *S. mirabilis* (145 x 10^3 cells/l), *Spirogyra quadricalamina* (92 x 10^2 cells/ml), *S. submaxima* (25 x 10^6 cells/l), *Zygema conspicuum* (796 x 10^5 cells/l), *Z. gangeticum* (413 x 10^5 cells/l).

Group V: Species observed only during summer and autumn:
- *Pinnularia gibba* (313 x 10^5 cells/l), *P. nobilis* (22 x 10^3 cells/l).

Group VI: Species observed only during autumn:
- *Cymbella gracilis* (10 x 10^2 cells/l), *Navicula rhynchocephala* (33 x 10^3 cells/l), *N. viridula* (22 x 10^3 cells/l).

Species occurring only below the surface
- *Anabaena circinalis* (113 x 10^3 cells/l), *A. sproides* (15 x 10^6 cells/l), *Lynphyba polysiphonae* (6 x 10^3 cells/l), *L. suzicola* (9 x 10^3 cells/l), *Microcystis ramosa* (5 x 10^3 cells/l), *M. robusta* (71 x 10^3 cells/l), *M. viridis* (47 x 10^6 cells/l), *Mycanthoccus sp.* (11 x 10^6 cells/l), *Tetrachloris merismopodiodes* (7 x 10^3 cells/l).

Group VII: Species observed intermittently throughout the year with maxima in autumn or winter:
- *Cymbella lacustris* (26 x 10^2 cells/l), *C. parcea* (22 x 10^3 cells/l), *Gomphonema ghosea* (12 x 10^3 cells/l), *Stauroneis anceps* (1 x 10^4 cells/l).
Group VIII: Species observed only during winter:

*Cymbella helvetica* (3 $\times 10^3$ cells/l.), *Eunotia arcus* (4 $\times 10^3$ cells/l.).

Group IX: Species observed in winter and spring seasons with maxima in spring season:

*Aphanizomenon flos-aquae* (1 $\times 10^5$ cells/l.), *Amphora affinis* (13 $\times 10^2$ cells/l.), *A. ovalis* (5 $\times 10^3$ cells/l.), *Anomoeoneis sorias* (38 $\times 10^2$ cells/l.), *Epithemia zebra* (45 $\times 10^2$ cells/l.), *Nitzschia palea* (32 $\times 10^2$ cells/l.), *Rhoicosphenia curvata* (8 $\times 10^3$ cells/l.), *Synechla rumpens* (7 $\times 10^2$ cells/l.).

Group X: Species observed during spring and autumn:

*Gomphonema parvulum* (15 $\times 10^2$ cells/l.)

Species occurring only below the surface

*Navicula gastrum* (7 $\times 10^3$ cells/l.).

Very few phytoplankton species were observed during winter. Two species (Group VIII) occurred only during winter and were eliminated with the increase in temperature. Even during the winter season, they were not abundant (NZNEEN 1974). There are certain species which appeared during mid-winter (Group IX), but their maximum concentrations were observed in spring. This means that these species require relatively high temperatures for their optimum growth. It is interesting to note that the species belonging to the above mentioned groups were all diatoms, except *Aphanizomenon flos-aquae*.

The number of species increased significantly during spring, both at the surface and below (NAZNEEN 1974). Species which appeared in spring are of two types. The first occurred during the spring and disappeared by the end of this season (Group I). These organisms seem to require relatively high temperatures with longer periods of bright sunshine for their propagation. They may be termed high temperature and high light intensity species. It is interesting to note that during this period, certain species of this group were observed only below the surface. It seems that they are well adapted to conditions of relatively low illumination. When the days have longer periods of bright sunshine (Fig. 1), the direct effect of radiations might cause their absence at the surface. The complete absence of these species in summer seems to be due to extremely poor light penetration, resulting from cloudy skies (Table 1) and a thick scum of *Microcystis aeruginosa* at the lake surface. Another factor requiring consideration is the repainting of the lake during late spring. It may be that mechanical disturbances are at least partly responsible for the floristic differences between spring and summer. Species of the second type appeared in spring and developed their largest populations either in spring or summer (Group II). Slightly low temperatures in spring appear to be compensated for by longer periods of bright sunshine. That is the reason that some species appearing in spring developed their highest population densities either in spring or in summer. These species may be termed high temperature species.

The presence of a larger number of species during spring and the sudden disappearance of many of them by the end of the season appears to be of interest. DUTHIE (1968) has suggested that a considerable number of epiphytic and epilithic diatom species can enter a lake with the spring runoff, but they never multiply and therefore rapidly disappear. A number of epiphytic diatoms have also been recorded in Kijnjar Lake. A few species appeared suddenly at one time in considerable numbers and then all at once disappeared. These sudden appearances and disappearances of the species seem to be due to water inflow, as suggested by DUTHIE (1968), in this case, spring runoff. Another factor which requires serious consideration is competition. It may be that with the onset of favourable temperature in spring, a large number of species resume growth, and, in due course, certain species overgrow and finally
displace others. It seems that in the present situation either or both of these factors, depending on the species, could be responsible for the sudden disappearances.

About 50% of the species which occurred only during summer (Group III) were myxophycean species. GEORGE (1962) has also noted that high temperature is the principal factor in the growth of Myxophyceae. Some rare species of the other two algal groups (Bacillariophyceae and Chlorophyceae) were also found during this period. Based on the range of temperature in which they can grow, all these species would be expected to occur in autumn, but it was found that they appeared suddenly for a short time and then disappeared (NAZNEEN 1974). It seems that they developed due to conditions of favourable temperature, but were unable to grow due to severe competition with the dominant and faster growing species, particularly Microcystis aeruginosa and Melosira granulata. Only a few species (Group V) were able to survive in spite of this severe competition and have been observed until autumn, but their occurrence was sporadic (NAZNEEN 1974). Some species (Group IV) grew throughout the year intermittently, showing that they could tolerate a wide range of temperature and light conditions, but their maximum growth took place during summer when the temperature was high.

The species which occurred only during autumn (Group VI) were also rare. They seem to require longer continuous periods of high temperatures for their reproduction, which may account for their absence in spring. It is interesting to note that during this period certain myxophycean species were absent at the surface and appeared only some distance below, perhaps due to a need to avoid excess light.

There are a few species (Group X) which appeared only during autumn and spring. This means that they require relatively high temperature and longer periods of bright sunshine for their propagation. While reduced light due to cloud cover may account for the total elimination of these species in summer, the role of increased interspecific competition during this season should not be ignored altogether.

There are certain species which were observed intermittently throughout the year, but their maximum concentrations occurred in autumn or winter (Group VII). These species seem to require low temperature for their optimum growth, but they have a wide range of temperature tolerance, just like the species which occurred throughout the year, but the maximum growth of which occurred in summer.

A significant concentration of phytoplankton was present throughout most of the year, due to the continuous growth of certain diatom species, including Melosira granulata, and of Microcystis aeruginosa, which exhibit "blooms" in summer.

Under normal conditions in enclosed water bodies of tropical impoundments, a continuous heavy population of phytoplankton, especially Microcystis aeruginosa, occurs throughout the year, with a bloom in summer (GANAPATI 1940). GEORGE (1962) has suggested that high temperature acts as a principal factor causing blooms of Myxophyceae. The pattern of phytoplankton distribution reported by GANAPATI (1940), however, is disrupted (Fig. 5) in Kinjhar Lake by certain mechanical disturbances during the annual repairing and cleaning periods (generally April or May); by the presence of an inlet and an outlet, which mainly affect the chemical conditions of the water; and finally by the growth of producers. The decrease in the phytoplankton population in Kinjhar Lake, caused by certain mechanical disturbances during April or May, was followed by a sudden rise in later months, due to favourable temperatures. The decrease in growth during November was not followed by a sudden increase because of unfavourable temperatures in the following winter months. It thus appeared that the growth of phytoplankton was more rapid during the high temperature period in the summer months.

McCORMIE (1953) argued that the water temperature may be a controlling factor for the growth of phytoplankton. These species possess certain temperature tolerance
The pattern of phytoplankton distribution in a closed water body and in Kinjhar Lake. The pattern of phytoplankton distribution (especially *Microcystis aeruginosa*) in Kinjhar Lake. The schematic representation of the pattern of *Microcystis aeruginosa*, which could be expected in a closed tropical water body, as observed by Ganapati (1940).

ranges. Between their upper and lower tolerance limits, the species are able to develop sudden pulses of reproductive activity when other factors, such as nutrient availability, are also favourable.

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8. Summary

The influence of various hydrological factors on the seasonal distribution of phytoplankton in Kinjhar Lake was studied. This water body is an artificial lake situated 120 km north of Karachi. The investigations were conducted from March 1968 to February 1971. The maximum atmospheric and water temperatures were observed in May and June; the minimum occurred in January. The abundance of phytoplankton, especially *Microcystis aeruginosa*, generally followed the seasonal changes in light and temperature. During this study, it was noted that in this tropical environment, the seasonal distribution of individual species cannot be described in terms of the four seasons. This is due to gradual changes in the interaction of light and temperature. Kinjhar Lake is highly eutrophic. In spite of their continuous utilization by phytoplankton and other plants, the nutrients were generally found to be present in excessive amounts throughout most of the year. Phosphorus and nitrogen, however, become limiting factors for phytoplankton during very short periods, when they are present in abnormally low concentrations. The supply of oxygen and carbon dioxide in the lake water was uninterrupted and adequate due to continuous movement of water by the wind action throughout most of the year. Besides the hydrological factors, mechanical disturbances also have an effect on the distribution pattern of the phytoplankton.
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