STUDIES ON PRIMARY PRODUCTION IN LAKE CHILKA

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PREFACE

The research work embodied in this dissertation has been carried out in the School of Environmental Sciences, Jawaharlal Nehru University, New Delhi. This work is original and has not been submitted in part or full for any other degree or diploma of any University.

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CONTENTS

INTRODUCTION

Biological productivity can no longer be considered a matter of simple academic interest, but of unquestioned importance for survival. The productivity and harvest of most of the world's terrestrial and aquatic environments must be increased if the world population is to have any real hope of having enough to eat. This increase is not possible unless we gain a much better understanding of the processes which control productivity at the level of primary producers.

The primary productivity of an ecosystem, or any part thereof is defined as the rate at which radiant energy is stored by photosynthetic and/or chemosynthetic activity of producer organisms in the form of organic substances which can be used as food and fuel materials. The four major successive steps in the production process are the following.

1. Gross primary productivity is the total rate of photo - synthesis, corrected for the organic matter used up in respiration. This is also known as total assimilation.

2. Net primary productivity is the rate of production of organic matter in plant tissues in excess of respiratory utilization by the plants. This is also called apparent photosynthesis or net assimilation.

3. Net community productivity is the rate of storage of organic matter not used by heterotrophs during the period under consideration.

4. Secondary productivity is the rates of energy storage at consumer level.

Primary productivity in aquatic systems provides the base of food web upon which all higher levels of the ecosystem depend. Lindeman (1942) (35) developed a trophic dynamic model of an aquatic ecosystem and introduced the concept of "energy flow" to describe the efficiency of energy transfer from one trophic level to the other. Some of the primary productivity is a source of energy for the next grazing level in the food chain. Phytoplankton communities, besides requiring a portion of their autotrophic production for respiration must also reserve a portion of it for the maintenance of their community structure (18, 37).

Lakes can be classified as oligotrophic (low productivity), mesotrophic (medium productivity), eutrophic (high productivity) and finally a bog stage (dystrophic) in which the lake has almost been filled in by weeds and the productivity has been greatly decreased (19).

Factors affecting primary production.

Primary production in an aquatic ecosystem depends upon light intensity, salinity and availability of nutrients and trace elements to the phytoplanktons.

Light: Light being a basic requirement for photosynthesis, primary production depends upto a large extent upon its intensity. In a typical oxygen bottle experiment Gaarder and Gran (1927) (15) were able to denote a depth, where the amount of O_2 produced by photosynthesis during the course of the experiment was exactly balanced by the amount of oxygen consumed by respiration. This depth where no effective production occurs, but where respiratory and photosynthetic activity just balance, has been termed as the compensation depth. Its extent depends on the transparency of the water. Light is very rapidly reduced in the sea, being partly absorbed and partly scattered.

Jenkin (1937) (27) working with the diatom Coscinodiscus excentricus observed that productivity of phytoplankton attains a linear relationship upto light intensity of 5000 Lux and reaches saturation at 20,000 Lux, beyond which light becomes inhibitory for photosynthesis.

Not only the intensity of light, but also the nature of electro-magnetic solar radiation changes while passing through a vertical water column in lake or in ocean. The intensity of a

beam of light entering water at right angles or normal to the surface of water is given by

$$I_s = I_0 e^{-ns}$$

or $\text{Ln } I_0 - \text{Ln } I_s = ns,$

where I_0 is the intensity of the beam as it crosses the water surface, I_s is the intensity at depth s and n a constant for any given wavelength, termed the extinction coefficient.

The absorption and transmission of light by pure water is given in Table-A. This can be expressed in terms of extinction coefficient n or as percentile transmission ($100e^{-n}$) or percentile absorption $[100(1-e^{-n})]$, the depth s being taken as one metre.

The Table-A denotes that the transmission is low and the extinction coefficient high in the infrared; there is a rapid increase in transmission between 740 and 700 nm and again at 600 nm to 580 nm in the orange (26). The transmission is maximal in a region about 460 nm in the blue, and falls very slowly in the violet, and more rapidly in the ultraviolet. However, the above relationship derived for pure water may not hold good for lake or ocean water which is very turbid containing organic, inorganic substances and microorganisms.

With the marked differential absorption of wavelengths of light in the sea, marine algae are not only adapted to photosynthesis

Table - A

The absorption and transmission of light in pure water.

Wave length	Extinction coefficient (n)	Percentile absorption $100\ (1-e^{-n})$
820	2.42	91.1
800	2.24	89.4
780	2.31	90.1
760	2.45	91.4
740	2.16	88.5
720	1.04	64.5
700	0.598	45.0
680	0.455	36.6
660	0.370	31.0
640	0.310	26.6
620	0.273	23.5
600	0.210	19.0
580	0.078	7. 0
560	0.040	3. 9
540	0.030	3. 0
520	0.016	1. 6
500	0.0075	0.777
480	0.0050	0. 52
460	0.0054	0. 52
440	0.0078	0. 79
420	0.0088	0. 92
400	0.0134	1. 63
380	0.0255	2. 10

at low light intensities having higher chlorophyll content but also possess carotenoids of different absorption maxima for efficient absorption of light at wavelengths not available for chlorophyll absorption at different depths.

Temperature: While light intensity must be of major significance in relation to primary production in the sea, other factors may also play a part. Temperature is probably of little direct importance for productivity since low temperatures reduce the respiratory needs of the plant cells and higher temperatures increase respiratory requirements. It is obvious that photosynthesis occurs at high efficiency in the Antarctic where the temperatures may be permanently below 0°C and equally well in tropical regions where temperatures approach 30°C (45). On mudflats in tropical region much higher temperatures may be experienced for at least part of the day. Experimentally it has been shown that in Skeletonema increased temperature may have a direct effect on photosynthetic rate, provided light saturation is achieved (10).

Salinity: Salinity variations can be shown experimentally to have an effect on photosynthetic rate. The marine phytoplanktons are adapted to different saline environments. For example, Curl and McLeod (1961) (10) found that Skeletonema had an optimum rate of photosynthesis at salinities ranging between 15‰ and 20‰, though the process could go on over as wide a range as 11‰ to 40‰. Braarud (1961) (5) demonstrated that some species of dino-

flagellates like Ceratium, Peridinium, Prorocentrum reproduce more actively at lowered salinities.

Nutrients:

Phosphorus: For many years the concentration of two major plant nutrients, nitrate and phosphate has been recognised as one of the major factors limiting primary production in the oceans. The cycle of phytoplankton growth in temperate latitudes with the marked spring and autumn peaks and the depression of production during summer has been linked with changes in nutrient levels. Several investigators (Cooper, 1933) (9), (Harvey, 1955) (23) have shown that lack of nitrate and phosphate, whichever is in shortest supply acts as a marked brake on phytoplankton production. The clearest demonstration of the relationship between a constant supply of nitrate and phosphate and primary production is provided by the major upwelling areas such as those of West Africa, Off Chile and Peru, and off the coast of California. In each region the relatively high concentrations of nitrate and phosphate are accompanied by rich growths of phytoplanktons (22).

Schindler (1971) (49) and Schindler et al. (1972) (50) have shown conclusively that in a group of small lakes of various types used specifically for nutrient studies, phosphorus was the nutrient which could most often be called the "limiting factor" for the growth of phytoplanktons and thus for eutrophication.

Work of Ketchum (1939) (31) has demonstrated that the growth of Nitzschia is unaffected as long as about 16 mg of phosphate-phosphorus/m^3 are present. At concentration of 5 mg/m^3 the rate of cell division fall off very rapidly.

It is to be noted that the growth determining internal phosphorus is dependent on the uptake rate which in turn is dependent on external phosphorus concentration. The uptake rate has its own set of controlling factors. It is noted that the absence of external phosphorus is not an indication of phosphorus limitation for phytoplankton because of their ability to store phosphate (43).

It is apparent that although inorganic orthophosphate may be in short supply, soluble and colloidal organic phosphates are part of the normal enzyme complement of algal cells, and some phytoplankton make use of phosphatase to hydrolyse organic phosphates in the water (43).

Nitrogen: Nitrogen is another major limiting nutrient for primary production in oceans as well as in certain fresh water systems (10, 45, 50). As with other major nutrients, the absolute requirement for nitrogen has been studied on several levels in order to explain: a) temporal and spatial variations in rate of production observed in nature and, b) the relative distribution of phytoplanktonic species. Active research is concerned with species variations in the concentration dependency of membrane

transport for the various combined nitrogen forms, rates of incorporation of nitrogen into cellular components, and the relationships between uptake, assimilation and growth in terms of cell number, cell nitrogen and total biomass. All of these relationships and processes are strongly coupled to other factors which vary within the physical system, such as light intensity and quality, temperature, concentration of other nutrients and growth factors, and the effects of higher trophic levels (43).

Phytoplanktons can take up combined nitrogen species at extremely low (0.1 uM) concentrations and against the negative gradient of ion indicating the occurence of active transport. When nitrate is present in larger amounts, luxury consumption or uptake in excess of the requirements for growth can occur, resulting in internal pools of unreduced nitrate (7).

The often quoted C:N:P ratio of 100:15:1 for phytoplankton has been examined (43). Since cell size and cell carbon increases during phosphorus limitation, the C:P ratio rises to 480:1 and N:P ratio rises to 35:1. The 100:15:1 ratio is reached when the cells are phosphorus limited at one-half to three-fourths of maximum growth. The ratio of N:Chlorophyll-a remains constant.

Minor nutrients: From the laboratory observations on primary production in sea-water, it has become obvious that a number of other elements normally present in trace amounts in sea-water

are also essential to healthy plant growth. Iron, manganese, copper, zinc, cobalt and molybdenum are usually considered as limiting trace elements (45). As the knowledge of the concentrations of these elements in the sea at different localities is very scanty, it is not easy to assess the limiting nature of each element on the productivity. The position is complicated by the fact that some of these elements such as Mn and Fe occur to a greater extent as particulate matter varying in size from colloidal aggregates to particles that may be retained by normal filtration. Indeed the amount of true ionic iron which can exist in sea-water is extremely small. Algal cells can make use of small particulate forms, for example of iron, and therefore, the question of whether such elements ever become limiting is even more doubtful (45).

Hubbunt and Rodman (1963) (24) have suggested that the sporadic blooms of neretic species in the open sea may be occasioned by the temporary presence of larger quantities of iron or similar nutrients which normally limit their distribution. However, the experiments of McAllister et al (1961) (36) have shown that blooming of coastal plankton species is not limited by trace metals like Fe, Cu, and Mn. Therefore it is extremely difficult to assess whether in particular any trace element is limiting in nature.

Methods for study of primary production

There are several methods for study of primary production. However, a few important methods to study primary production in isolated samples of natural communities have been mentioned below.

Measurement of standing crop: Standing crop refers to the part of biological production per unit area or per unit volume that is physically present as biomass and that is not lost in respiration. Standing crop measurements over a period of time give an indirect measure of productivity in terms of yield. Plankton, microscopic floating plants and animals, can be collected in a plankton net and may be counted under a microscope or weighed.

The annual production of most aquatic macrophytes can generally be estimated satisfactorily by maximal seasonal biomass measurements. However, biomass is not directly indicative of the gross production, or the net production (60, 61) and for better understanding, measurements of photosynthetic and respiratory rates are required.

Light and dark bottle technique measuring oxygen changes: When subsamples of a phytoplankton population in light and dark bottles are hanged for a certain period during the day time, the initial concentration of dissolved oxygen (c_1) can be expected to fall to a lower value (c_2) in the darkened bottles by respiration and to be changed to another value (c_3) in the clear bottles according

to the difference between photosynthetic production and respiratory consumption (54). If other processes involving oxygen (eg. photo-oxidative consumption) are absent or can be neglected and if it is assumed that respiratory consumption is not altered by illumination, then the difference $(c_1 - c_2)$ represents the respiratory activity per unit volume over the time interval involved, the difference $(c_3 - c_1)$ the net photosynthetic activity and their sum $(c_3 - c_1) + (c_1 - c_2) = (c_3 - c_2)$, the gross photosynthetic activity. On this basis it is possible to estimate approximately the gross photosynthesis directly from the difference on concentration, between the clear and dark bottles, but further knowledge of the initial concentration is needed for estimates of respiration and net photosynthesis, since respiration as measured with this technique represents community respiration, rather than 'phytoplankton respiration' alone. The above method and its applications have been described in detail by Strickland and Parsons (1968) (56).

The ^{14}C light and dark bottle technique: In the ^{14}C technique, the ^{14}C is incorporated into the organic matter of phytoplanktons during photosynthesis and the rate of incorporation measures the primary productivity. If the total CO_2 content of experimental water is known and if a definite amount of $^{14}CO_2$ is added to water, then by determining the content of ^{14}C in the plankton after the experiment, the total amount of carbon assimilated can be

calculated. It is only necessary to multiply the amount of ^{14}C found with a factor corresponding to the ratio between the total CO_2 of the water and the total $^{14}CO_2$ added at the beginning of the experiment. The excellent sensitivity of the method can be increased further by applying several correction factors (54).

Oxygen versus ^{14}C methodology: There is uncertainty as to whether the radiocarbon method measures net photosynthesis or something between the net and gross photosynthesis (55). Fixation of ^{14}C from bicarbonate does not give a true measure of total carbon fixation if organic compounds are assimilated at the same time. There is increasing evidence that photoassimilation of organic compounds by algae may sometimes be appreciable. During the experimental period some amount of ^{14}C-labelled organic compounds such as glycolate may be excreted out of algal cells (52).

In the oxygen method as mentioned above, gross photosynthesis can be ascertained, however, with the assumption that the rate of respiration remains the same in light and dark. Net photosynthesis cannot be assessed very correctly because of community respiration, and any attempt to separate phytoplanktons from zooplanktons may damage the former. However, in short term experiments community respiration can be kept at a low pace. Provided that primary production measurements are made for small duration, the oxygen method seems the more reliable (57).

In the present experiments, the oxygen method for determining photosynthetic rate has been followed due to convenience in its handling in the field.

Primary production by macrophytes

In an aquatic ecosystem, the amount of organic matter produced by the marginal macrophytes may be far greater than that produced by the planktons. Mann (1973) (39) has reviewed the productivity in coastal water and estuarine macrophytes. Most of his estimates of net primary production by macrophytes are higher than the upper estimates of 500 gC/m^2/year for estuarine planktons (40). Wassman and Ramus (1973) (58) suggest that the maximum potential production of green macro alga Codium fragile is about 4.7 KgC/m^2/year in Long island sound. Mann (1972) (38) states "seaweeds, sea grasses and mangroves are much more productive than phytoplankton in the immediate vicinity of the coast. Their rate of carbon fixation on a unit area basis, may be an order of magnitude greater than the phytoplankton, and they are sufficiently widespread on a global scale, for it to be reasonably certain that an understanding of the food chains based on marine macrophytes is essential to an understanding of coastal ecosystems".

The crop growth rate: The crop growth rate i.e. daily rates of change in biomass ultimately depend on photosynthetic capacity but many other factors, such as biomass, self-shading, variations

in irradiance and proportions of non-photosynthetic tissue are involved. The emergent plants possess a high growth rate (25-48 g dry weight/m^2/day) during the peak season of their growth, whereas the submerged plants during their peak growing seasons have a reduced rate of growth (2-10 g dry weight/m^2/day) (60).

Annual production of biomass: Many authors (Seidel, 1959) (51), (Kvet, 1971) (34), (Boyd, 1969) (4) have reported that biomasses of aerial shoots of emergent plants in temperate zone range from 1.5 - 3.5 Kg dry weight/m^2/year. The species involved include Butomus umbellatus, Phragmites communis, Schoenoplectus lacustris, Sparganium erectus and Typha angustifolia. All these have extensive rhizome systems which were not always sampled, but there is enough data in the literature to show that the underground parts are often two to five times the weight of aerial parts (59). Kaul (1971) (30) found aerial shoot biomasses of Typha angustata and Phragmites communis of 3.5 - 4.7 Kg dry weight/m^2/year in Kashmir lakes.

On the otherhand the submerged plants produce at a rate of 0.5 Kg dry weight/m^2/year in temperate zones. Unfortunately there is not sufficient information on the biomass of tropical submerged fresh water plants except those of odum (1957) (42), Ganapati (1971)(15), Gopal (1975) (20). The marine submerged macrophytes like kelps and giant kelps i.e. brown algae of the genera Laminaria

and Macrocystis achieve annual net production in the range of 1000 - 2000 gC/m^2. In tropical marine water the turtle grass Thalassia may have an annual productivity of 500 - 1500 gC/m^2 (40).

Major chemical constituents of macrophytes

A good deal of information exists as to the chemical composition of water plants. Some quite striking differences between aquatic and terrestrial plants seem to exist and curious dissimilarities between fairly closely related species are well documented. The potassium content of aquatic angiosperms is little greater than that of terrestrial. The sodium content is usually variable, usually but not always less than potassium (25). Calcium and magnesium content of aquatic macrophytes sometimes differ from that of terrestrial plants. Ca is generally accumulated in aquatic plants as $CaCo_3$ (25).

Phosphorus and nitrogen are generally believed to be the most important limiting elements in fresh waters. Experimental studies suggest that when the nitrogen content of the dry matter is below 1.3%, the element is limiting in the presence of abundant phosphorus and when the phosphorus content is below 0.1%, phosphorus is limiting in presence of adequate nitrogen (16). In most analysis of water plants, iron is somewhat in excess of manganese in contrast to land plants (25).

Saline environment of marine aquatic plants poses a problem in their mineral uptake and distribution, which differs from that of terrestrial plants and freshwater aquatic macrophytes. Marine macrophytes are capable of regulating mineral uptake and maintaining ionic balances in the cells. However, unfortunately due to lack of enough data, it is not possible to attribute the extent of role of individual salts in maintaining ionic balance in the cells of aquatic macrophytes.

AIM OF THE PRESENT INVESTIGATION

The present study primarily aims at the following:

a) The Estimation of the net primary production by phytoplanktons of the lake Chilka in the month of June 1977.

b) The correlation of primary production with environmental parameters like nutrient status, trace element contents and salinity level of lake water.

Besides studying the above parameters attempts have also been made to measure standing crop of a few selected widespread macrophytes. A few important chemical constituents of above macrophytes have also been analyzed. The physiography of the lake, the widespread flora and fauna of the lake have not been studiediin detail.

PHYSIOGRAPHY OF THE LAKE CHILKA

The lake Chilka, situated in the State of Orissa, is a brackish water lagoon on the east coast of Indian peninsula (Fig.1). The geographical position of the lake is between latitudes 19° 28' and 19° 54' N and longitudes 85° 6' and 85° 35' E. Its area is about 350 sq. miles.

The lake consists of two parts: i) an outer channel opening into the sea, ii) and the main body of water. The outer channel is peculiar in that, it runs parallel to both lagoon and sea for some miles before joining the latter. Its total length is about twelve miles and the breadth is nearly one mile. The actual mouth of this channel changes from time to time both in position and size. On several occasions the mouth is completely blocked.

The main area of the Chilka lake is the real lagoon and it is roughly pear shaped. The length of the lake is forty miles. The broadest point in the lake lies in Puri district at the north-eastern extremity.

Islands of the lake: In the main area of the lake there are a number of rocky islands. Malaban is the largest island, being covered with marshy grasses, its area being eight square miles. The lake has several other islands like Chiragua, Badakuda, Sankuda, Samal, Kalijai, Malati Kuda, Baruni Kuda etc. On

Fig. 1: Index map showing the position of the lake Chilka in Indian peninsula.

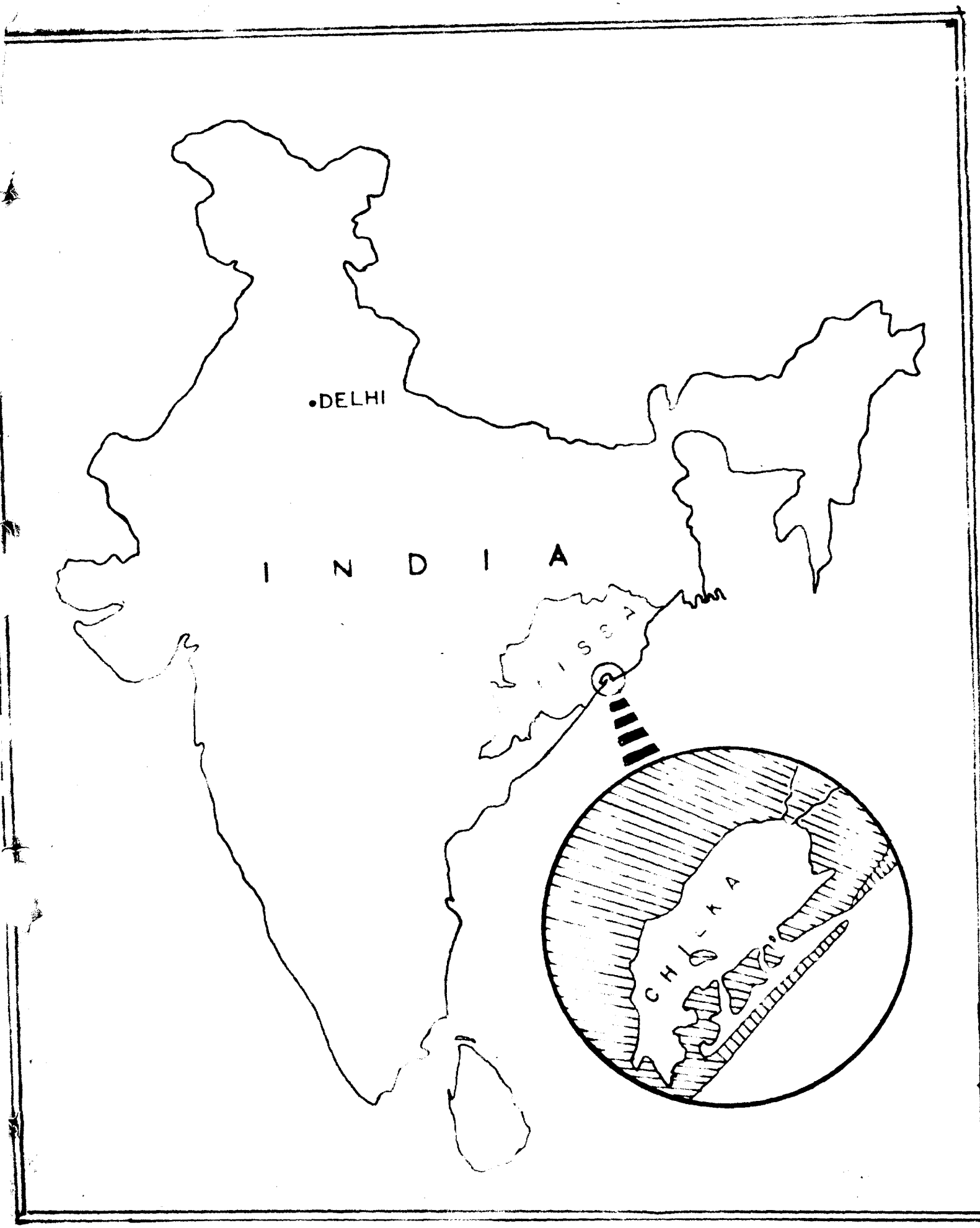

FIG. 1

only one island Samal there is inhabitation and the village is also called Samal. This island is having a few cultivated fields and the major occupation of the inhabitants is fishing.

The island Badakuda is full of wild plants belonging to Leguminosae, Verbenaceae, Utricaceae, Passifloraceae, Solanaceae and Convolvulaceae etc. There is a deserted building in this island. Similar kind of vegetation is also found in Sankuda, the sister island of Badakuda. The Chiragua island (Chadhaihaga) looks brownish white, due to continued deposition of faeces of numerous birds who take shelter especially in winter on this small beautiful stone body. The island Kalijai, which is situated at the Southern side of the stretched arm of Jatia Hills is a beautiful island, which divides the lake into a northern wider outer body and a southern narrower, relatively undisturbed water bay. This island has a temple called Kalijai. The island is also covered with wild flora, belonging to leguminosae, convolvulaceae, verbenaceae, labiatae and solanaceae etc. The Gopakuda island, situated near Khallikote, is very close to the western bank of the lake. This island is having a few mango trees, which obstruct the narrow water channel at the western side of the island, when viewed from the lake and therefore the island looks like the shore of the lake. The islands of the outer

channel including Barunikuda are having sand banks. They support a scanty growth of short grasses. However, Baruni Kuda is thickly covered with grasses and supports a few stunted shrubs.

Shores: The shores of the Chilka lake have considerable variety of characters. At some places the slope of the shore towards the edge of the lake is covered with smooth green grass fields and leafy trees. The major vegetation the shore is mesophytic, with a few xerophytic plants creeping in the areas which are covered with sand dunes.

Shore line index: One aspect of shore line which is of significance is its development, which is a potential effect of littoral processes in the lake, with the area remaining constant. This measure is stated as $D_L = \frac{L}{2\sqrt{\pi A}}$, when A = area of the lake, L = shore line and D_L = shore line index. In other words it is the ratio of length of the shore line to the length of the circumference of a circle of area equal to that of the lake. Chilka lake has the shore line of 132 miles with shore line index (D_L) = 1.75, which reflects the high magnitude of littoral processes on the lake shore.

At the northern end of the main area, the silts are brought down by branches of Mahanadi river of which most important is the river Daya. A narrow stream salia also joins the lake at the northern part.

Bottom: The bottom of the main area is muddy, while that of outer channel is sandy. The mud forms two quite distinct layers, one of which practically remains undisturbed, while the other is usually held suspended in water and only deposited in very sheltered places or at winter season, when there is practically no wave in the lake due to very low wind velocity. The floating layer is of course very finely divided and therefore stains water with a dirty clay colour. Its occasional deposition is an unfavourable factor in the life of many sessile organisms. The permanent layer is gray and of a clayey consistency. It is mixed with a considerable amount of decayed organic matter which sometimes stains it black. In the inner part of the outer channel there is a great mixture of mud and sand, some of the latter being black and extremely heavy. In the outer part of the outer channel that runs parallel to the Bay of Bengal, the bottom is composed of almost pure yellow sand.

Depth: Depths of the lake measured at different parts during the month of June 1977 show a wide variation. The lake is quite shallow in the northern part. The depth of this area ranges between 0.5 metre and 1 metre. The deeper part of the lake lies near Kalijai and towards Rambha bay where the depth is 2 metres or more, 2.75 metres being the maximum. The depth

of the middle part of the lake is roughly 1.5 metres but at some places it ranges between 1 and 2.4 metres.

The depth of the lake steadily starts declining after Malaban towards north. Thus the main water body of the lake can be divided broadly into two parts: the shallow northern part and deeper southern part.

VEGETATION OF THE LAKE

In many parts of the lake, especially in deeper parts, the aquatic vegetation is scanty. However, in less deeper parts of the lake an abundant amount of the vegetation occurs.

Mostly in north-western parts of the lake the species Potamogeton pectinatus, L. with slender grass-like leaves grow luxuriantly and makes a thick interwoven network in which fishes and other aquatic flora and fauna take shelter. This plant dies in rainy season. The new growth appears in autumn. This plant flowers in December, and fruits are very much intact with the plants, upto the month of April.

Description of Potamogeton pectinatus, L.

The above species belong to the family of Naiadaceae.

Stem: Stem is filiform, copiously dicholomously branched, 1' to 6' in height, glabrous, green.

Leaves: Filiform, submerged, alternate, 1" to 6" in length, about 0.1" in breadth, green, slightly thickened inrolled margins, 1-3 nerved, stipules adnate to the leaf sheath.

Inflorescence: Flowers interruptedly whorled in a spike, length of the spike is 0.2" to 1".

Flowers: Flowers bisexual, sepals 4, anthers 4, sessile.

Fruits: Drupules, obovoid, ventrally slightly convex, with strong lateral ridges. The seed germinates while still attached to the fruit in the parent plant.

In south eastern, south-western, as well as Nalaban side of the lake the species Halophila ovata, Gaud is widely distributed. The above species creeps along the bottom sending up at short intervals stems of four to six inches high. This species bears relatively large ovate leaves which form a favourite shelter for a few sessible animals. Small portions of this plant which float on water get detached by wave action, by divi..ng ducks and other water-birds. This plant is found at all the times of the year.

Description of Halophila ovata, Gaud.

Class: Monocotyledones.

Order: Hydrocharideae

Tribe: Thalassieae (Hydrocharitaceae)

Salt water submerged plants, prostrate.

Leaves: In pairs, pinnately veined, oval in shape, penninerved, petioled, thin, colour varies from whitish green to green.

Flowers: Unisexual, solitary.

Male flowers: Pedicelled, sepals 3, petals 0, anthers 3, alternate with sepals, anthers subsessile, linear oblong, extrose.

Female flowers: Sessile, sepals 3, minute, ovary beaked, one celled, inferior, style 3, filiform, ovules 2-seriate on (2) parietal placentas.

Fruits: Included, subglobose, beaked.

Seeds: Many, subglobose, testa membranous.

Among semiaquatic flowering plants by far the most conspicuous is the emergent reed Phragmites karka, Trin, that covers north-western parts of the lake beyond Kalupara. This reed is also found in Nalaban and occurs scantily in Sankuda near Rambha area. During rains it reaches a height of three metres. Half of the above aquatic flowering plant, emerges above water surface. The plant also exhibits tillering habit.

Description of Phragmites karka Trin.

This species belongs to family Gramineae and group Arundineae (reeds).

Tall, large grasses, 5' - 10' in height.

Stem: Close jointed hollow stems, green, emergent, exhibits tillering habit.

Leaves: Stiff, erect, almost submerged, 1' - 2' in length and 1" in breadth, tapers upwards.

Inflorescence: A panicle, erect, lanceolate.

Flower: Spikelets grey, glumes, linear, lanceolate, pedicels glabrous.

Other descriptions of the flower could not be made, because of nonavailability of fresh flowers.

One economically important vegetation of the lake is the red alga Gracilaria, an important source for agar-agar production. It grows mostly on the rock surfaces. It occurs abundantly at Pathara and to a lesser degree at Kalijai, Jatia hills, Badakuda and Sankuda.

Species of Dinoflagellates, have a wide occurence in the lake. Diatoms constitute the benthic flora.

Oscillatoria occure very abundantly floating freely in the lake.

Another important algal vegetation is Spirogyra which adheres to the rock substratum or to some submerged plants. Submerged rocks and stones are usually coated with simple and branched filamentous algae, but their growth is not always luxuriant.

GENERAL CHARACTERS OF THE LAKE FAUNA

The lake fauna can be grouped under the following headings(1):

1. Mud fauna
2. Sand fauna
3. Rock fauna
4. Weed fauna
5. Free swimming organisms
6. Planktons.

1. Mud fauna: Mud fauna constitutes a very important part of the fauna, because a major proportion of the bottom of the lake is covered with mud. Among the mud-dwellers are included coelenterates, polychaet worms, a large proportion of the molluscs, Decapods and other crustacean worms. Dead shells of molluscs are abundantly found in the mud.

2. Sand fauna: The arenicolous animals of the lake are mainly confined to the outer part of the outer channel. Sponges, oligochaete worms, polychaets, decapod, crustacea and molluscs also occur abundantly in this part of the lake.

3. Rock fauna: The occurence of rock fauna is relatively much smaller compared to other kind of fauna. General sponges, coelenterates, molluscs occur on the rock surface of the lake.

4. Weed fauna: The weeds like Halophila ovata, and Potamogeton pectinatus offer shelter to the majority of the weed fauna.

Young fishes and crabs, take shelter in the thickly woven network of Potamogeton. Colenterates and sponges adhere to the leaves of Halophila.

5. Free swimming organisms: These include fishes, string-rays, crustaceans and ctenophores. White jelly fishes with long tentacles are also seen floating in water. Water birds swim in the lake sometimes in groups and can sink in water and hide for sometime. They generally take shelter on the rocks of the lake.

6. Planktons: Copepods and larval molluscs greatly predominate the planktonic fauna.

MATERIALS AND METHODS

Determination of dissolved oxygen

The method followed in determination of dissolved oxygen is a modification of classical Winkler's procedure (56).

Sampling of water from the lake

300 ml BOD bottles were rinsed with lake water four times, before being filled up. BOD bottles were then filled with surface lake water and extreme care was taken, so that no water buble remained inside the bottle. As soon as water was collected, the bottle was tightly stoppered inside the water and then brought out of lake water.

Reagents

1. Manganese sulphate reagent: 365 g of $MnSO_4.H_2O$, was dissolved in distilled water and made upto one litre.

2. Alkaline iodide solution: 500 g of sodium hydroxide was dissolved in 500 ml of distilled water. 300 g of potassium iodide was dissolved in 450 ml of distilled water. Both the solutions were mixed and stored in dark in a brown opaque bottle.

3. Standard thiosulphate solution: A standard 0.01 N sodium thiosulphate solution was prepared.

4. Starch indicator solution: 2 g of soluble starch was suspended in 300 ml of distilled water. 20% solution of NaOH

was added to it with vigorous stirring, until the solution become clear, and the solution was allowed to stand for 2 hours. Concentrated HCl was added to the above solution until it became just acidic to litmus paper. 2 ml of glacial acetic acid was then added to the above solution, and diluted to one litre with distilled water.

Procedure

Stopper was removed from the completely filled BOD bottle, 1.0 ml of $MnSO_4$ reagent was added to it followed by 1.0 ml of alkaline iodide solution. The bottle was restoppered immediately and the contents of the bottle were mixed thoroughly by shaking until the precipitate manganous-manganic hydroxide was evenly dispersed. The precipitate was then allowed to settle and 2.5 ml of concentrated HCl was added to the bottle by opening the stopper and again restoppered and mixed thoroughly by shaking until the precipitate was completely dissolved.

50 ml of above solution in BOD bottle was taken out by a 50 ml pipette. 5 ml of starch indicator was added to the above 50 ml solution and this forms a blue colour of starch iodide. This was titrated against 0.01 N $Na_2S_2O_3$ solution taken in a 10 ml burette having graduation of 0.05 ml until a colourless end point was reached.

Calculations

If X is the ml of $Na_2S_2O_5$ solution used,

50 ml is the amount of solution taken for titration,

0.01 is the normality of $Na_2S_2O_5$ solution,

then,

$$mgO_2/litre = \frac{X \times 0.01 \times 1000 \times 8}{50 \times 298/300}$$

mgO_2/m^3 = 1000 x mgO_2/litre.

Determination of Nitrite (NO_2^-) in lake water.

A modified method of Bendschneider and Robinson for analysis of sea water was followed (56).

Sampling procedure of lake water and storage

Samples were collected from the lake water in 300 ml polythylene bottles. It was filtered through a millipore set. The samples were stored not more than twelve hours after collection.

Reagents

Sulphanilamide solution: 5 g of sulphanilamide was dissolved in 300 ml of water and 50 ml of concentrated HCl was added to it with stirring. The above solution was diluted to 500 ml and stored.

N-(1-Napthyl)-ethylenediamine hydrochloride solution: 0.5 g of reagent was dissolved in 100 ml of distilled water and diluted to 500 ml.

Procedure

40 ml of the millipore filtered lake water was taken in a 50 ml graduated flask and diluted to about 46 ml with distilled water. 1.0 ml of sulphanilamide solution was added to it and mixed thoroughly and allowed to react for 5 minutes. Then 1 ml of Naphthyl ethylene diamine solution was added to it and thoroughly mixed. The sample was diluted to 50 ml. A red coloured solution was formed which was completed in 10 minutes. The optical density of the above solution was measured at 543 nm. The blank was determined by repeating the above procedure with distilled water.

A standard curve was prepared using KNO_2 as standard reagent. The calculation was made as ug - NO_2^- - N/ml.

Determination of Nitrate (NO_3^-) in lake water.

A modified method of Morris and Riley was followed for the determination of Nitrate (NO_3^-) (56).

Sample collection and storage.

The samples were collected in 300 ml of polythelene bottles. The collected water was filtered through a millipore set. The samples were not stored more than 12 hours after collection.

Reagents

1. A concentrated ammonium chloride solution was prepared in distilled water and stored in a plastic bottle.

2. Sulphanilamide solution: 5 g of sulphanilamide was dissolved in 300 ml of distilled water followed by 50 ml of con. HCl with stirring. The above solution was diluted to 500 ml by distilled water.

3. Cadmium-copper filings column: Alloy of cadmium-copper was filled in upto 10 cm of glass tube of 1 cm diameter. Care was taken that the filings were compact.

4. N-(1-Napthyl)-ethylene diamine Hydrochloride solution: 0.5 g of the above reagent was dissolved in 500 ml of distilled water and stored in a dark bottle.

Procedure

100 ml of millipore filtered lake water was taken and to it 2.0 ml of concentrated ammonium chloride solution was added. The above solution was mixed and then poured successively in volumes of 5, 5, 10 and 20 ml of the sample into the column, allowing each volume to be drained, before adding the next. The eluates were discarded. This ensured replacement of the solution in the column, if any, with the new sample. 40 ml of reduced sample was collected from the column in a 50 ml of measuring graduated flask.

To it 1.0 ml of sulphanilamide solution was added soon. The reagent was allowed to react for five minutes and not more than eight minutes. 1.0 ml of Napthyl ethylene diamine solution was added to it and was mixed thoroughly by shaking. The solution was diluted to 50 ml by adding distilled water. The colour reaction was complete after 15 minutes. The optical density was measured at 543 nm. Blank was prepared by repeating the above process with distilled water instead of lake water.

Since the above method NO_3^- was reduced to NO_2^-, the NO_3^- determined represented total NO_3^- and NO_2^- present in water. Therefore, first NO_2^- was determined and then this amount was deducted from total NO_2^- determined after reduction to represent the amount of NO_3^- that was reduced to NO_2^-.

Determination of soluble inorganic phosphorus in lake water.

The procedure followed was a modified method of Murphy and Kiley (56). The sensitive range of the method is 3 ug to 150 ug P/litre. However, precision is at 10 ug/litre level.

Sampling of lake water.

The sampling of lake water was done in 300 ml. Polythelene bottles, rinsed twice with the lake water to be analysed. The analysis was done within 12 hours of collection of samples.

Reagents

1. Ammonium molybdate solution: 15 g of ammonium molybdate was

dissolved in 500 ml of distilled water. It was stored in plastic bottles.

2. Sulphuric acid solution: 140 ml of con. H_2SO_4 was added to 900 ml of distilled water. The solution was cooled and was stored in a glass bottle.

3. Ascorbic acid solution: 27 g of ascorbic acid was dissolved in 500 ml of distilled water. The solution was stored in room temperature not more than one week.

4. Pottassium antimony tartarate: 0.34 g of potassium antimony tartarate was dissolved in 250 ml of water. It was stored in a plastic bottle.

5. Mixed reagent: 100 ml of ammonium molybdate, 250 ml of sulphuric acid, 100 ml of ascorbic acid, and 50 ml of potassium tartarate, were mixed together. It was not stored more than 6 hours.

Procedure

40 ml of millipore filtered water was taken in a 50 ml graduated flask. 8 ml of mixed reagent was added to it and diluted to 50 ml. After 15 minutes, a blue colour was formed, were official density was measured at 885 nm. The blank was repeated as above with distilled water instead of lake water.

Determination of salinity in the lake water.

Salinity of the lake was determined by the specific conductivity of lake water measured by a conductivity bridge.

Collection of sample

Lake water was collected in 200 ml polythelene bottles rinsed thrice by the lake water, the conductivity of which was to be determined.

Procedure

The specific conductivity of standard sea water was determined by the conductivity bridge in mMho. The specific conductance of lake water was also measured by the above conductivity bridge. Then they were converted in terms of salinity as ‰ of standard sea water. The normal salinity of standard sea water is 35‰.

The percentage of salinity of sea water calculated for lake water was converted to g of salt present per litre of lake water (gram/litre denoted as ‰).

Determination of trace elements in lake water

The trace elements Zn, Cu, and Fe were determined by atomic absorption spectrophotometre.

Sample collection

The water sample was collected in 500 ml polythelene bottles from different parts of the lake. 1 ml of concentrated H_2SO_4 was added to water in order to check the adsorption of trace metals by polythelene container.

Procedure

Each sample was filtered by millipore set. The millipore filter was not touched by hand or metallic forceps.

For the determination of each trace element specific cathodes were introduced. The atomic absorption spectrophotometer was supplied with air-acetylene fuel.

50 ml of water samples were taken in very neatly cleaned 100 ml beakers and the volume was reduced to exactly 10 ml. Then the samples were analysed by atomic absorption spectrophotometer. The values obtained were divided by 5 to determine the real content of trace elements of lake water measured in PPM.

Estimation of Nitrogen of plant parts by Kieldal's apparatus.

Reagents

1. Concentrated H_2SO_4, A.R. (Sp. Gr. 1.84).

2. Digestion mixture: Ten parts of K_2SO_4 and one part of $CuSO_4$ were mixed thoroughly and was grinded to powder form. Then 0.1 part of selenium metal powder was added mixed thoroughly and stored in abbottle.

3. Standard H_2SO_4: 1.4 ml of above concentrated H_2SO_4 was dissolved in 100 ml of distilled water. The normality of the acid was exactly determined by titrating against standard sodium carbonate using methyl orange as indicator.

4. Mixed indicator:

a) 0.5 g of bromocresol green was dissolved in 10 ml of 0.1 (N) NaOH and made upto 500 ml with distilled water.

b) 0.25 g of methyl red was dissolved in 7.5 ml of 0.1 (N) NaOH and made upto 250 ml by distilled water.

c) 150 ml of bromocresol green solution, 50 ml of methyl red solution were mixed together and made upto 400 ml. with absolute alcohol. It was stored in a brown stoppered bottle.

5. Boric acid solution: 50 g of boric acid was dissolved in 500 ml of boiling distilled water, and made upto 2500 ml. To this 50 ml of mixed indicator was added and it was stored in a brown opaque bottle.

6. Sodium hydroxide: One kg. of NaOH was added slowly with stirring to 2 litres of distilled water. It was allowed to stand overnight. It was filtered through glass wool and stored in a brown bottle.

Procedure

0.1 g of dried and powdered plant material was weighed into a 30 ml Kjeldal's flask. A pinch of digestion mixture and 2.5 ml of concentrated H_2SO_4 were added. The flask was then kept on a digestion heating chamber and was heated till the forthing ceased. When the digestion was complete and solution became clear, the flask was taken out of the chamber and cooled.

The digest was transferred to distillation unit with four washings. 10 ml of NaOH solution was added to it. Ammonia was steam distilled for five minutes into 10 mlcof boric acid solution. The colour of boric acid turned green during ammonia distillation and after the distillation was complete, it was titrated against 0.05 NH_2 SO_4, to a pink end point.

Calculation: $N\% = \frac{14 \times N \times \text{Titration value} \times 100}{\text{Weight in mg.}}$

when N = Normality of H_2 SO_4 (0.05N).

Estimation of chlorophyll in plants

The leaves of potomogaton pectinatus, Halophilia ovata and the green peel of emergent hollow stems were separated from the plants. Chlorophyll from 100 mg of the green leaves or peels were extracted in 10 ml of 80% acetone and centrifuged, with parafilm covering the mouth of the centrifuge tubes in order to check evaporation of acetone. The optical density was measured taking 80% acetone as blank, at 649 nm and 665 nm. The total chlorophyll content was estimated according to Arnon(2).

Estimation of total phosphorus in plant parts.

Reagents

1. a) 25 g of ammonium molybdate was dissolved in 150 ml of water. It was heated to 60°C and cooled.

b) 136 ml con. H_2SO_4 was added to 150 ml of distilled water and was cooled.

c) Both the above solutions were mixed, cooled, made upto 500 ml by distilled water.

2. To 500 ml of distilled water in a beaker 15 g of sodium bisulphate, 1.5 g of sodium sulphite, and 0.5 g of 1-amino-2-Napthol sulphanic acid were added in succession. The total volume was made upto 500 ml.

3. One triacid mixture of nitric acid, perchloric acid and sulphuric acid was prepared in the ratio of 20:3:1.5.

Procedure

0.5 g of dried and powdered plant material was digested in 12 ml of tri acid mixture. The above digestion was carried out in digestion heating chamber. When the digestion was complete, the digest was transferred to a 25 ml volumetric flask with four washings and was made upto volume by double distilled water.

2 ml of the aliquot was taken out of 25 ml flask into a 50 ml volumetric flask. It was diluted by adding 25 ml of water. Then 2 ml of reagent-1 was added followed by 2 ml of reagent-2. The content of the flasks were chilled in ice cold water and a blue colour developed completely after 15 minutes. The sample was made upto 50 ml by adding distilled water. The optical density was measured at 660 nm.

KH_2PO_4 was used as standard reagent.

Determination of potassium and calcium content of macrophytes.

100 mg of dry powdered plant material was digested with HCl and was filtered through No. 44 Whatman filter paper into a 50 ml flask and made upto volume. The final extract contained 1% HCl.

The extracts were then compared in the flame photometer for K and Ca against standard solutions containing exactly the same amount of hydrochloric acid.

Determination of magnesium content of macrophytes.

Magnesium was determined in plant parts collorimetrically using Mg SO_4 as standard reagent.

Reagents

Morgan's reagent: 100 g of sodium acetate and 30 ml of acetic acid were dissolved in distilled water and made upto 1 litre.

Tartarate reagent: 10 g of sodium hydrogen tartarate, 10 g of manitol, 2.5 g of hydrazine sulphate were dissolved in 1 litre of water.

Sodium hydroxide: 150 g of pure sodium hydroxide pellets were dissolved in 1 litre of distilled water.

Dye reagent: 0.09 g of thiazol yellow was dissolved in 1 litre of distilled water and 2 drops of sodium hydroxide was added to it and filtered after 24 hours.

Dye solvent: 600 ml of n-butyl alcohol was mixed with 400 ml of ethyl alcohol.

Magnesium stock reagent: 4.054 g of pure $MgSO_4.7H_2O$ was dissolved in one litre of Morgan's reagent.

Magnesium standard solution: 50 ml of stock solution was diluted to one litre with Morgan's reagent.

Tri acid mixture: One tri acid mixture of nitric acid, perchloric acid and sulphuric acid was prepared in the ratio of 20:3:1.5.

Procedure

0.5 g of dried and powdered plant material was digested in 12 ml of tri acid mixture. After the completion of digestion, the digest was transferred to a 25 ml volumetric flask with four washings, and was made upto volume by double distilled water.

An aliquot of 15 ml was taken and 5 ml of tartarate reagent 5 ml of dye reagent and 20 ml of sodium hydroxide were added to it successively with stirring and left over night. 50 ml of dye solvent was added to it mixed thoroughly and phase separation was allowed to take place. After 30 minutes, the upper layer was decanted off to a conical flask containing 0.5 ml of acetone. It was compared with colour of standards within 30 minutes.

Determination of iron and manganese content of plant materials.

0.5 g of plant material was digested in by tri acid mixture of HNO_3:$HClO_4$:H_2SO_4 = 20:5:1.5. After the completion of digestion, the digest was transferred to a 25 ml volumetric flask with four washings and was made upto volume by double distilled water and filtered.

Fe and Mn were determined by atomic absorption spectrophotometer from the above extract, supplying air-acetylene fuel.

Estimation of primary production in the lake by phytoplanktons.

Sampling of water: Water was collected from surface and desired depth by a water samples and light and dark BOD bottles were filled in, taking care that no air buble remained inside the bottles. One initial bottle (IB) of water was also collected.

Procedure

Dark bottles were painted black and also were covered by aluminium foils. These light and dark bottles were hanged in the lake in duplicate at desired depths by a thread. The depth profile of productivity was studied, where the depth of the lake was 1 metre or more. The bottles were illuminated for 4 hours and sometimes 6 hours. After the exposure period, oxygen was

immediately fixed in both light bottles (LB) and dark bottles (DB) by the $MnSO_4$ and alkaline KI as described for oxygen analysis.

Oxygen of an initial BOD bottle (IB) filled during sample collection was also fixed while hanging the light and dark bottles in the lake. The precipitates were dissolved in 2.5 ml of con. HCl and then titrated against 0.01 (N) sodium thiosulphate solution as described before for oxygen analysis (56).

Calculations:

Gross photosynthesis = Titration value of light bottle (LB) - Titration value of dark bottle (DB).

Net photosynthesis = Titration value of light bottle (LB) - Titration value of initial bottle (IB).

Community respiration = Titration value of initial bottle (IB) - Titration value of dark bottle (DB).

$$mgO_2/litre/hour = \frac{\text{Titration value} \times \text{normality of } Na_2S_2O_3 \times 1000 \times 8}{\text{Ml of solution take for titration} \times \frac{298}{300} \times \text{duration of exposure in hours.}}$$

$mgO_2/m^3/hour$ = mgO_2/litre/hour x 1000.

Assuming that photosynthetic quotient to be unity for phytoplanktons,

$mgC/m^3/hour$ = 0.375 x $mgO_2/m^3/hour$ (54).

Determination of primary production by macrophytes of the lake.

The standing crop of four species of aquatic macrophytes: Halophila ovata, Potamogeton pectinatus, Phragmites karka and Gracilaria were determined, by uprooting the plants. These plants were uprooted, from 0.25 m^2 of land area measured by one wooden frame, specifically designed for it. These plants were washed in the lake water and then dried and dry weight was taken. These observations were made at different parts of the lake and from each place five replicates were taken. In a few selected places of the lake, sampling was repeated after one month, to study the growth rate of two species. The biomass was expressed as gram dry weight/m^2 of land area.

Determination of location of various stations in the lake.

While moving in a motor boat or country boat in the lake, the boats were stopped at the desired spots of the lake and anchored to prevent drifting. The bearings were taken by the Brunton Compass and the positions were plotted on the map of the lake. At some selected places depending upon the depth, locality and accessibility to the place, station numbers were denoted. From these selected spots, productivity measurement and chemical analysis of water etc. were done.

RESULTS

STUDY OF PRIMARY PRODUCTION IN THE LAKE CHILKA.

The primary production of the lake was studied at different parts of the lake by hanging light and dark bottles in the lake as described in the chapter of materials and methods. Due to several limitations, primary production in all parts of the lake could not be studied. The outer channel, because of its low depth in the month of June, could not be surveyed at all due to its inaccessibility from the main body of the lake. The study of different kind of depth profile for primary production was done in a few selected and easily accessible sites. Primary production studies in the northern part of the lake where the depth was less than 1 meter, could not be done at very many places. It was confined to a few places, easility accessible by a country boat.

Gross and net photosynthesis measured at different stations of the lake at the surface: Gross photosynthesis, net photosynthesis and community respiration, expressed as µgC/l/hour are given in Table-1. A comparison of the data shows that net and gross photosynthesis was lowest in the middle part of the lake (station Nos. 17-33). The same were bit higher in the southern part of the lake (station Nos. 1-16) and highest in the northern part of the lake (station Nos. 34-39). From station Nos. 1-33 the community respiration invariably equalled the net photo-

synthesis. The same was appreciably lower than net photosynthesis in the northern part of the lake (station Nos. 34-39)(Fig-2).

Calibration of the method for study of depth profile of net photosynthesis in the lake: Three sets of experiments were done to calibrate the method for study of depth profile. Two convenient stations were chosen for such calibration study (Table-2).

In the first set of experiments, the samples were collected in light and dark bottles from different depths (i.e. surface, one metre and one and half metres) by a water-sampler and were hanged at corresponding depth.

In the second set of experiments, samples were collected from different depths and were hanged at the surface of the lake.

In the third set of experiments, the light and dark bottles were filled with surface water and hanged at different depths.

As shown in Table-2, the net and gross primary production and community respiration rates were same in water samples collected from different depths and hanged at the surface (second set of experiments). However, when they were hanged at depths from which they were collected, the net and gross primary photosynthesis were reduced whereas the respiration rate remained

the same (first set of experiments). The samples collected from the surface and hanged at different depths (third set of experiments) exhibited the same rate of photosynthesis and respiration as those of the samples collected at different depths and hanged at corresponding depths.

The above observations showed that the distribution of planktons through the vertical column was uniform and the reduced rate of photosynthesis at different depths was due to limitation of light intensity. However the respiration rate remained almost constant, at all depths measured.

Therefore, for further experiments on photosynthesis, the light and dark bottles were filled in with surface water and hanged at different depths to study the limitations of net photosynthesis by light intensity.

Study of depth profile of net photosynthesis. Based on conclusions drawn from the above experiments, further experiments on depth profile of net photosynthesis were conducted by hanging the bottles filled with surface water, hanged at different depths. The results of study of depth profile of net photosynthesis has been tabulated in Table-3. The net photosynthesis decreased with increased depth. At one metre depth, the photosynthesis decreased by more than half, and at 1.5 metre depth at some places photosynthesis still could be observed at a much

reduced rate and some other places it could not be observed at all. The total net photosynthesis of the one square metre of water column was highest at the northern part of the lake. The lowest net photosynthesis was recorded at the middle part and highest a t the northern part of the lake.

Calculation of total net photosynthesis of the lake: Calculations of total net photosynthesis of the lake per day and average primary production /m^2/day during the month of June 1977, have been made in Table-4. It indicates that total net photosynthesis of the lake /day was 768675 KgC/day and average net primary production by phytoplanktons of the lake was 1.14 gC/m^2/day. It is to be noted that the calculations of the area of the lake excluded the outer channel and other shallow parts of the lake, where productivity could not be measured.

NITRITE AND NITRATE CONCENTRATION AT DIFFERENT PARTS OF THE LAKE MEASURED AT SURFACE.

Nitrite and nitrate concentrations measured in different parts of the lake are given in Table-5. The NO_2^- concentration was relatively higher in the northern part of the lake ranging from 18 ugN/litre to 36 ugN/litre (station Nos. 31-39). It was relatively lower in the southern part of the lake ranging from 12 ugN/litre to 20 ugN/litre (station Nos. 1-16). Nitrite level was below the sensitivity limit of the detection of the procedure followed, in the middle part of the lake (station Nos. 17-30), and at mouth of the lake near Arakakuda.

The nitrate concentration was always higher than that of nitrite. The NO_3^- was highest in the northern part of the lake ranging from 89 ugN/litre to 245 ugN/litre (station Nos. 31-39). The nitrate was relativdy lower in the southern part of the lake ranging from 58 ugN/litre to 81 ugN/litre (station Nos. 1-16). It was lowest in the middle of the lake where its concentration ranged from 8 ugN/litre to 20 ugN/litre (station Nos. 19-30). NO_3^- concentration near lake mouth was also low i.e. 12 ugN/litre.

INORGANIC SOLUBLE PHOSPHORUS CONTENT OF THE LAKE WATER.

The level of soluble inorganic phosphate in almost all parts of the lake (where phosphorus content was measured) was found to be beyond the limit of detection by the methodology followed. Other methods which were more sensitive for detection of phosphorus could not be followed, due to the nonavailability of required instruments.

SALINITY OF LAKE WATER.

Salinity of the lake measured in June 1977 is given in Table-6 and Figure 3.

A detailed study of salinity of surface samples measured, revealed that the salinity was highest in the middle of the lake, and it further increased towards the outer channel connecting the lake with the Bay of Bengal. Since entrance area near Nagarmukh to the outer channel was very shallow, during the period

of survey the motor boat could not enter it and therefore the salinity of the channel could not be measured. However, the mouth of the lake at Arakakuda could be approached by land route and salinity at the mouth was almost equivalent to sea water. The lowest salinity was recorded from extreme northern part of the lake, where the rivers Daya and Bhargavi bring water into the lake.

The lowest salinity recorded in the northern part of the lake ranged from 10.2‰ to 11.6‰ (station Nos. 34-38). The higher salinity recorded in the southern part of the lake ranged from 16‰ to 16.8‰ (station Nos. 1-16). The highest salinity was found to be in the middle part of the lake ranging from 17.6‰ to 28‰ (station Nos. 17-33). The salinity at Arakakuda, the lake mouth was 35‰.

OXYGEN CONTENT OF LAKE WATER.

The oxygen concentrations at different stations of the lake determined from surface water samples, are given in Table-7. The solubility of oxygen is affected by the salinity. Higher the salinity, lower the solubility.

A comparison of oxygen concentration at different stations of the lake showed that the middle part (station Nos. 17-30), except a few stretches around Nalaban, was relatively lower in

oxygen concentration. The southern part of the lake (station Nos. 1-16) was slightly higher in oxygen than the middle part. Dissolved oxygen concentration was found to be highest in the northern part of the lake.(station Nos. 31-39).

TRACE ELEMENT CONTENTS OF LAKE WATER MEASURED AT SURFACE.

Only a few trace elements (Fe, Zn and Cu) have been measured from surface samples of lake water.

Iron concentration at different parts of the lake: Iron concentration measured by atomic absorption spectrophotometer ranged from 0.12 to 0.32 PPM and is given in Table-8. Iron concentration was found quite variable at different stations. However, a higher iron concentration was recorded from Kalupara, Balugaon, Nalaban, mouth of the river Daya and isband complex of Sanakuda, Badkuda and Samal located at the southern part of the lake.

Zinc content of the lake water: The concentration of zinc recorded at different parts of the lake are tabulated in Table-9. Zinc concentration was found to be higher near Rambha area of the lake and relatively lower near Kalupara region. The lowest concentration was recorded from the middle part of the lake. The minimum and maximum zinc concentration determined from lake water was 0.025 and 0.19 PPM respectively.

Copper concentration in the lake water: Concentration of copper measured at different parts of the lake are given in Table-10. The copper concentrqation was found to be uniform at different parts of the lake. Highest concentration of copper was recorded from stretches of Balugaon and Malaban. The minimum and maximum copper content determined from lake water was 0.02 PPM and 0.04 PPM respectively.

Depth profile of distribution of nutrients and dissolved oxygen: The dissolved oxygen, nitrite and nitrate contents were measured in samples collected from surface and from one metre and 1.5 metre depths at three easily accessible selected places of the lake. The distribution of the above soluble water components was found to be almost uniform in a vertical water column (Table-11). This indicated a thorough vertical mixing of water.

THE CORRELATION STUDY OF PRIMARY PRODUCTION.

The gross photosynthesis of the lake has been correlated with the nutrient status, salinity level and other trace element contents of lake water (Table-12). The productivity is positively correlated with nitrogen content of lake water (correlation coefficient = +0.9602). It is also positively correlated with iron content of lake water (correlation coefficient = +0.6433). It is negatively correlated with salinity level of lake water (correlation coefficient = -0.8566). Productivity has not been

significantly correlated with zinc and copper concentrations of lake water.

PRIMARY PRODUCTION BY MACROPHYTES OF THE LAKE.

Standing crop expressed as gram dry weight/m^2 of land area of three angiospermic species i.e. Potamogeton pectinatus, Halophila ovata and Phragmites Karka and one species of red alga Gracilaria was measured in the month of June 1977, at different easily accessible parts of the lake. The red alga Gracilaria was found attached to the substratum of rock surface. The places from which the macrophytes are collected have been allocated the status of substations as shown in Table-13 and Fig. 2 . Among the macrophytes the reed swamp Phragmites produced the highest amount ranging from 880 g dry weight/m^2 land area to 1440 g dry weight/g^2 of land area. Potamogeton came second in the production list whose primary production ranged from 540-750 g dry weight/m^2 of land area. The third macrophyte, a red alga produced 132-480 g dry weight/m^2. The fourth macrophyte Halophila ovata had the production capacity ranging from 80 to 196 g dry weight/m^2 of land area.

The crop growth rate of macrophytes: Due to difficulties in easy access to parts of the lake where Phragmites and Gracilaria grow only the growth rate of Halophila and Potamogeton could be measured. The observations were taken during the month of

June 1977, from different parts of the lake in five replicates and average figures were calculated. The net production during one month was divided by thirty to give primary production/m^2/day. As given in Table-14, Halophila ovata had the net primary production rate of 0.556 g dry weight/m^2/day, whereas Potamogeton had the production rate of 2.03 g dry weight/m^2/day.

Chlorophyll content of aquatic angiosperms: The chlorophyll contents of three aquatic angiosperms are given in Table-15. The variation in chlorophyll contents among the aquatic angiosperms was 25% or less. The chlorophyll content of the emergent reed swamp Phragmites was obtained from the green peels of the emerging reeds. The chlorophyll content of other two plants was determined from the leaves.

Nitrogen content of macrophytes: Table-16 records the nitrogen content of four macrophytes. The nitrogen content was lowest (1.5%) in Phragmites, the emergent plant and highest (1.95%) in Potamogeton, the submerged one.

Phosphorus content of water-plants: The phosphorus content of the macrophytes are given in Table-17. The variation in phosphorus content was quite significant which ranged from 0.06% for Phragmites to 0.235% for Halophila.

N:P ratio of macrophytes: N:P ratio of the macrophytes are

recorded in Table-18. The variation in the ratio was more than three fold, the lowest being 7.2 and highest being 25.0.

Potassium, calcium and magnesium content of aquatic macrophytes: Potassium content of aquatic angiosperms ranged from 0.45% to 2.4%. However, the submerged red alga Gracilaria was having a very high potassium content (12.2%).

Calcium content of aquatic macrophytes ranged from 0.15% to 0.35%.

Magnesium content of aquatic angiosperms ranged from 0.7% to 1.37% whereas Gracilaria possessed a low Mg content (0.57%). The Ca:Mg ratio ranged from 0.140 to 0.491 (Table-19).

Iron and manganese content of aquatic macrophytes: The range of iron content of aquatic macrophytes was from 0.03% to 0.74% whereas that of Mn was from 0.013% to 0.102%. The Mn:Fe ratio of plants ranged from 0.028 to 0.433 (Table-20).

Table - 1

Net and gross photosynthesis and community respiration of surface phytoplanktonic samples measured at different parts of the lake.

Station No.	Net photo-synthesis (µgC/l/hr)	Gross photo synthesis (µgC/l/hr)	Community respiration (µgC/l/hr)
1.	50	100	50
2.	45	90	45
4.	40	80	40
5.	45	90	45
7.	40	80	40
10.	45	90	45
15.	35	70	35
17.	20	40	20
19.	20	40	20
22.	15	30	15
23.	10	20	10
24.	20	40	20
28.	25	50	25
29.	20	40	20
31.	40	80	40
33.	35	70	35
34.	347	574	227
35.	310	510	200
36.	298	498	200
37.	320	530	210
38.	340	560	220

Table - 2

Depth profile of occurence of photosynthesis and respiration at different experimental conditions.

Station No.	Water depth at the station (metre)	Description of the experiment	Depth from which samples were collected	Depth at which samples were hanged	Net photo-synthesis. (µgC/l/hr)	Gross photo-synthesis. (µgC/l/hr)	Community respiration (µgC/l/hr)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1.	1.5	Samples collected from different depths and hanged at corresponding depth. (Experiment set up-1)	Surface	Surface	50	100	50
1.	1.5	-do-	1 m.	1 m.	20	70	50
1.	1.5	-do-	1.5 m.	1.5 m.	10	60	50
2.	1.5	-do-	Surface	Surface	45	90	45
2.	1.5	-do-	1 m.	1 m.	15	60	45
2.	1.5	-do-	1.5 m.	1.5 m.	5	50	45
1.	1.5	Samples collected from different depths and hanged at surface.(Experiment set up-2)	Surface	Surface	50	100	50
1.	1.5	-do-	1 m.	-do-	50	100	50
1.	1.5	-do-	1.5 m.	-do-	50	100	50
2.	1.5	-do-	Surface	-do-	45	90	45
2.	1.5	-do-	1 m.	-do-	45	90	45
2.	1.5	-do-	1.5 m.	-do-	45	90	45
1.	1.5	Samples collected from the surface and hanged at different depths. (Exp. set up-3)	Surface	Surface	50	100	50
1.	1.5	-do-	-do-	1 m.	20	70	50
1.	1.5	-do-	-do-	1.5 m.	10	60	50
2.	1.5	-do-	-do-	Surface	45	90	45
2.	1.5	-do-	-do-	1 m.	15	60	45
2.	1.5	-do-	-do-	1.5 m.	5	50	45

Table - 3

Depth Profile of Net Photosynthesis at different parts of the Lake.

Station No.	Depth at the station (metre)	Net photosynthesis at surface (µgC/l/hr)	Net photo synthesis at 1 m. depth. (µgC/l/hr)	Net photosynthesis at 1.5 m. depth. (µgC/l/hr)	Net photosynthesis at 2m. depth. (µgC/l/hr)	Average net photosynthesis. (µgC/l/hr)	Total net photosynthesis of water column having productive capacity. (µgC/m²/hr.)
1.	2.00	50	20	5	0	25.0	37.5
2.	2.00	45	15	5	0	21.6	32.4
4.	1.50	40	15	5	-	20.0	30.0
5.	2.25	45	15	5	0	21.6	32.4
7.	1.00	40	15	-	-	27.5	27.5
10.	2.50	50	20	10	0	26.6	39.9
11.	3.00	35	15	5	0	18.3	27.45
15.	2.90	35	15	5	0	18.3	27.45
						Total	254.6
						mean	31.8
17.	2.70	20	5	0	0	12.5	12.5
19.	2.60	20	5	0	0	12.5	12.5
22.	2.00	15	5	0	0	10.0	10.0
25.	2.20	15	5	0	0	10.0	10.0
24.	1.00	20	5	-	-	12.5	42.5
28.	1.50	25	5	0	-	15.0	15.0
29.	1.50	20	5	0	-	12.5	12.5
31.	1.50	40	10	4	-	18.0	27.0
33.	1.50	35	10	0	-	22.5	22.5
						Total	134.50
						mean	14.95
34.	1.00	347	221	-	-	284.0	284.0
35.	1.00	310	190	-	-	250.0	250.0
36.	1.00	298	190	-	-	244.0	244.0
37.	1.00	320	200	-	-	260.0	260.0
38.	1.00	340	210	-	-	275.0	275.0
						Total	1313.0
						mean	262.6

Table - 4

Calculation of total net productivity/day and average primary productivity/m^2/day by phytoplanktons present in the lake. (Calculation of the area of the lake excludes the outer channel and other shallow parts of the lake where productivity could not be measured.)

Calculation of the area of the lake.

Area of the northern part	=	189 sq. kilometres
Area of the middle part	=	346 sq. kilometres
Area of the southern part	=	136 sq. kilometres
Total area of the lake	=	671 sq. kilometres

Net productivity in the northern part/m^2/hour = 262.6 mgC

Total net productivity of the northern part
= 262.6 x 189000000
= 49651400000 mgC/h
= 49651.4 KgC/h.

Total net productivity of the northern part during 13 hour photoperiod = 49651.4 x 13 = 645208 KgC/day.

Net productivity in the middle part/m^2/hour = 14.95 mgC

Total net productivity of the middle part
= 14.95 x 346000000
= 5172700000 mgC/h
= 5172.7 KgC/h.

Total net productivity of the middle part during 13 hour photoperiod = 5172.7 x 13 = 67245 KgC/day.

Net productivity in the southern part/m^2/hour = 31.8 mgC

Total net productivity of the middle part
= 31.8 x 136000000
= 4324800000 mgC/h
= 4324.8 KgC/h.

(cont'd)

Table - 4 (cont'd)

Total net productivity of the southern part during 13 hour photoperiod	= 4524.8 x 13	= 56222 KgC/day.
Hence total net productivity of the lake		= 768675 KgC/day.
Average net primary productivity of the lake	= 768675000 gC/671000000 m^2 = 1.14 $gC/m^2/day$.	

Table - 5

Nitrite and Nitrate content of the lake water at different stations measured from surface samples.

Station No.	Nitrite (µgN/l)	Nitrate (µgN/l)	Station No.	Nitrite (µgN/l)	Nitrate (µgN/l)
1.	12.0	81.0	21.	Below the limit of detection.	20.0
2.	18.7	60.0	22.	-do-	8.0
3.	18.7	62.0	23.	-do-	8.0
4.	18.5	61.0	24.	-do-	11.0
5.	18.7	62.0	25.	-do-	19.0
6.	17.5	60.0	26.	-do-	19.0
7.	16.0	60.0	27.	-do-	12.0
8.	15.0	58.0	28.	-do-	12.0
9.	15.0	58.0	29.	-do-	18.0
10.	15.0	60.0	30.	-do-	20.0
11.	16.0	61.0	31.	18.0	95.0
12.	20.0	64.0	32.	18.0	89.0
13.	14.0	60.0	33.	19.0	90.0
14.	15.0	62.0	34.	35.0	240.0
15.	17.0	59.0	35.	32.0	210.0
16.	18.0	67.0	36.	31.0	200.0
17.	Below the limit of detection.	12.0	37.	35.0	240.0
18.	-do-	11.0	38.	36.0	235.0
19.	-do-	12.0	39.	35.0	240.0
20.	-do-	13.0	40.	Below the limit of detection.	12.0

Table - 6

Salinity of lake water at different stations measured from surface samples.

Station No.	Salinity (‰)	Station No.	Salinity (‰)
1.	16.0	21.	19.0
2.	16.0	22.	19.0
3.	16.2	23.	19.0
4.	16.2	24.	22.0
5.	16.2	25.	22.2
6.	16.0	26.	23.0
7.	16.2	27.	28.0
8.	16.4	28.	22.2
9.	16.4	29.	22.4
10.	16.4	30.	22.6
11.	16.2	31.	19.0
12.	16.2	32.	19.0
13.	16.4	33.	18.0
14.	16.6	34.	11.2
15.	16.8	35.	11.6
16.	16.8	36.	11.4
17.	17.8	37.	10.8
18.	17.6	38.	10.6
19.	17.8	39.	10.2
20.	18.0	40.	35.0

Table - 7

Dissolved oxygen content of lake water, solubility of oxygen at the salinity of the station and its saturation percentage.

Station No.	Dissolved oxygen (mgO_2/l)	Salinity at the station. (‰)	Solubility of oxygen at corresponding salinity at 30°C. (mgO_2/l)	Percentage of saturation.
1.	7.5	16.0	6.85	109
2.	7.3	16.0	6.85	106
3.	7.2	16.2	6.85	105
4.	7.0	16.2	6.85	102
5.	7.0	16.2	6.85	102
7.	6.9	16.2	6.85	101
8.	6.8	16.4	6.85	99
10.	6.8	16.4	6.85	99
11.	6.6	16.2	6.85	96
13.	6.8	16.4	6.85	99
15.	6.6	16.8	6.80	97
16.	6.7	16.8	6.80	99
17.	6.4	17.8	6.71	95
18.	6.3	17.6	6.71	94
19.	6.5	17.8	6.71	97
23.	6.0	19.0	6.71	89
24.	7.2	22.0	6.64	108
28.	6.8	22.2	6.64	102
29.	6.8	22.4	6.64	102
31.	8.0	19.0	6.70	119
32.	8.2	19.0	6.70	122
33.	8.0	16.0	6.85	117
34.	9.2	11.2	7.06	130
35.	9.1	11.6	7.06	129
36.	9.0	11.4	7.06	127
37.	9.2	10.8	7.06	130
38.	9.2	10.6	7.14	129

Table - 8

Iron concentration determined from surface sample at different stations of the lake.

Station No.	Iron concentration (PPM)
1.	0.16
2.	0.17
3.	0.16
4.	0.15
5.	0.16
7.	0.20
8.	0.21
10.	0.20
11.	0.19
13.	0.17
15.	0.16
17.	0.16
18.	0.14
19.	0.13
20.	0.12
22.	0.13
23.	0.13
24.	0.20
25.	0.20
26.	0.20
28.	0.20
29.	0.19
31.	0.16
33.	0.16
34.	0.32
35.	0.30
36.	0.29
37.	0.17
38.	0.16
39.	0.15

Table - 9

Zinc concentration from different stations of the lake measured from surface samples.

Station No.	Zinc concentration (PPM)
1.	0.190
2.	0.150
3.	0.140
4.	0.095
5.	0.090
7.	0.095
8.	0.070
10.	0.050
11.	0.040
13.	0.030
15.	0.030
17.	0.030
19.	0.020
20.	0.025
22.	0.030
23.	0.035
24.	0.030
25.	0.035
26.	0.030
28.	0.040
29.	0.070
31.	0.075
33.	0.125
34.	0.120
35.	0.120
36.	0.120
37.	0.010
38.	0.060
39.	0.060

Table - 10

Concentration of copper in surface water of the lake measured at different stations.

Station No.	Copper concentration(PPM)
1.	0.020
2.	0.020
3.	0.025
4.	0.020
5.	0.025
7.	0.020
8.	0.025
10.	0.025
11.	0.020
13.	0.025
15.	0.020
17.	0.025
19.	0.020
20.	0.020
22.	0.040
23.	0.035
24.	0.035
25.	0.030
26.	0.020
28.	0.025
29.	0.020
31.	0.025
33.	0.020
34.	0.025
35.	0.020
36.	0.025
37.	0.020
38.	0.025
39.	0.025

Table - 11

Depth profile of distribution of nutrients and dissolved oxygen

Station No.	Dissolved substance.	Concentration at surface.	Concentration at 1 m. depth.	Concentration at 1.5 m. depth.
1.	NO_3^- ($\mu gN/l$)	81.0	82.0	83.0
	NO_2^- ($\mu gN/l$)	12.5	12.5	13.0
	O_2 (mg/l)	7.5	7.4	7.3
2.	NO_3^- ($\mu gN/l$)	60.0	60.0	61.0
	NO_2^- ($\mu gN/l$)	18.7	18.0	18.0
	O_2 (mg/l)	7.3	7.2	7.1
5.	NO_3^- ($\mu gN/l$)	62.0	60.0	61.0
	NO_2^- ($\mu gN/l$)	18.7	18.5	18.0
	O_2 (mg/l)	7.0	7.0	6.9

Table - 12

Correlation of primary production with salinity, nitrogen, zinc, copper and iron content of the lake water.

Station No.	Gross photo-synthesis (μgC/l/hr)	Nitrogen concentration (NO_3^- + NO_2^-) (μgN/l)	Salinity (‰)	Zinc (PPM)	Copper (PPM)	Iron (PPM)
1.	100	93.0	16.0	0.190	0.020	0.16
2.	90	78.7	16.0	0.150	0.020	0.17
4.	80	79.7	16.2	0.095	0.020	0.15
5.	90	80.7	16.2	0.090	0.025	0.16
7.	80	76.0	16.2	0.095	0.020	0.20
10.	100	75.0	16.4	0.050	0.025	0.20
15.	70	76.0	16.8	0.030	0.020	0.16
17.	40	12.0	17.8	0.030	0.025	0.16
19.	40	12.0	17.8	0.020	0.020	0.15
22.	30	8.0	19.0	0.030	0.020	0.13
23.	20	8.0	19.0	0.030	0.035	0.15
24.	40	11.0	22.0	0.030	0.035	0.20
28.	50	12.0	22.2	0.030	0.025	0.20
29.	40	18.0	22.4	0.040	0.020	0.19
31.	80	113.0	19.0	0.070	0.025	0.16
33.	70	109.0	16.0	0.075	0.020	0.16
34.	574	275.0	11.2	0.125	0.025	0.32
35.	510	242.0	11.6	0.120	0.020	0.30
36.	498	231.0	11.4	0.120	0.025	0.29
37.	530	275.0	10.8	0.010	0.020	0.17
38.	560	271.0	10.6	0,060	0.025	0.16
Correlation coefficient of independent variables with prodnotivity.		+0.9602	-0.8666	+0.2505	-0.1057	+0.6455

Table - 13

Standing crop of the macrophytes measured during June 1977, at different substations of the lake (the figures are the mean of five replicates).

Serial No.	Species	Substation	Standing crop of macrophyte. (g dry weight/m^2).
1.	Halophila	A_1	114
2.	-do-	A_2	130
3.	-do-	A_3	196
4.	-do-	A_4	100
5.	-do-	A_5	120
6.	-do-	A_6	100
7.	-do-	A_7	85
8.	-do-	A_8	180
9.	Potamogeton	B_1	750
10.	-do-	B_2	750
11.	-do-	B_3	700
12.	-do-	B_4	680
13.	-do-	B_5	650
14.	-do-	B_6	540
15.	-do-	B_7	630
16.	Phragmites	C_1	1440
17.	-do-	C_2	1080
18.	-do-	C_3	900
19.	-do-	C_4	880
20.	-do-	C_5	1120
21.	-do-	C_6	900
22.	Gracilaria	D_1	132
23.	-do-	D_2	480
24.	-do-	D_3	188
25.	-do-	D_4	132

Table - 14

Rate of net primary production by two macrophytes during the month of June 1977.

Species	Sub-station No.	Biomass on the 1st June 1977 (g dry wt/m^2)	Biomass on the 30th June 1977 (g dry wt/m^2)	Net primary production in one month (g dry wt/m^2)		Rate of primary production (g dry wt/m^2/day)
Halophila	A_1	100	114	14		0.48
-do-	A_2	114	130	16		0.53
-do-	A_3	176	196	20		0.60
					Total	1.67
					Mean	0.556
Potamogeton	B_1	685	750	65		2.16
-do-	B_2	690	750	60		2.00
-do-	B_3	642	700	58		1.93
					Total	6.09
					Mean	2.03

Table - 15

Chlorophyll content of aquatic angiosperms

Serial No.	Species	Chlorophyll content (µg. chl./g fresh wt.)
1.	Halophila	677
2.	Potamogeton	517
3.	Phragmites	601

Table - 16

Nitrogen content of the macrophytes expressed as percentage of dry weight.

Serial No.	Species	Nitrogen percentage
1.	Halophila	1.69
2.	Potamogeton	1.95
3.	Enhalus	1.50
4.	Gracilaria	1.70

Table - 17

Phosphorus content of macrophytes expressed as percentage of dry weight.

Serial No.	Species	Phosphorus percentage
1.	Halophila	0.235
2.	Potamogeton	0.160
3.	Phragmites	0.060
4.	Gracilaria	0.135

Table - 18

N/P ratio of the macrophytes

Serial No.	Species	N/P ratio
1.	Potamogeton	12.2
2.	Halophila	7.2
3.	Phragmites	25.0
4.	Gracilaria	12.6

Table - 19

Potassium, calcium and magnesium content of aquatic macrophytes expressed as percentage of dry weight.

Sl. No.	Species	Potassium (%)	Calcium (%)	Magnesium (%)	Ca:Mg ratio
1.	Phragmites	0.45	0.15	0.70	0.214
2.	Potamogeton	1.67	0.16	1.15	0.140
3.	Halophila	2.40	0.35	1.37	0.250
4.	Gracilaria	12.20	0.28	0.57	0.491

Table - 20

Iron and Manganese content of aquatic macrophytes expressed as percentage of dry weight.

Sl.No.	Species	Iron (%)	Manganese (%)	Mn:Fe ratio
1.	Phragmites	0.030	0.0130	0.433
2.	Potamogeton	0.700	0.0198	0.028
3.	Halophila	0.740	0.1020	0.137
4.	Gracilaria	0.276	0.0140	0.051

DISCUSSION

Primary production in the lake.

A study of primary production in the lake reveals that the rate of respiration equals the rate of net photosynthesis in most of the stations examined except station No. 34-38, where it is less (Table-1). This shows that the high rate of respiration from station Nos. 1 to 29 is perhaps due to high zooplanktonic O_2 uptake. The lower rate of respiration than net photosynthesis at station Nos. 34-38 is perhaps due to reduced presence of zooplankton in this area. However, mineralization may be another important factor for such discrepancy which has not been taken into account.

From Table-2 it is apparent that there is a thorough vertical mixing of water and therefore the planktons are almost evenly dispersed in it and productivity at higher depths should be limited by light intensity. It is apparent from Table-3 that photosynthetic zones are limited to 1.5 m depth at some places and to 1 m only at some other places.

The northern part of the lake (station Nos. 34-38) is highly productive (262.6 $mgC/m^2/hour$) as compared with the rest of the lake (Table-3). This may be due to higher nutrient status (coefficient of correlation = +0.9602) and low salinity levels (coefficient of correlation = -0.8666), probably caused

by fresh water along with nutrients coming from the River Daya. The reduced productivity rate of 31.8 mgC/m^2/hour in the southern part (station Nos. 1-16) and 14.9 mgC/m^2/hour in the middle part (station Nos. 17-33) of the lake is probably due to lower nutrients and higher salinity levels which may be inhibitory to algal growth (Table-12). Table-4 indicates that total net production by the phytoplanktons of the lake per day is 768675 KgC, measured in the month of June 1977. The average net primary productivity by the phytoplanktons of the lake is 1.14 gC/m^2/day. However, in absence of studies on seasonal variation of primary production, the above figures cannot be taken as representative rate of daily net primary production.

Thus though a wide spread variation in the productivity of the lake does exist, the lake can be divided broadly into northern eutrophic and southern mesotrophic regions (Fig-2).

NO_3^- and NO_2^- content of the lake water.

The lake Chilka water has been analysed for estimation of NO_2^- and NO_3^- from surface samples. However, NH_3 estimation has not been done due to certain practical difficulties. While comparing the southern part of the lake with the middle of the lake NO_3^- and NO_2^- concentrations are fairly higher in the former (Table-5). The net productivity in the southern part of the

lake is also higher than that of the middle of the lake.

In the northern part of the lake, the NO_2^- and NO_3^- content is highest, where the net photosynthesis is also highest (Table-12). The higher nitrogen content in this low lying area may be due to high wave action which is able to mix water thoroughly with the soft bottom of the lake. Sewage effluents from the river Daya, perhaps also contributes nutrient for higher algal growth in this region (Fig. 2.).

Thus a closer survey of NO_2^- and NO_3^- content, and primary production in the lake reveals a positive correlation (coefficient of correlation = +0.9602), among them although the reasons why there exists a differential distribution of the above nutrients in the lake remain practically unresolved.

Soluble inorganic phosphorus content of lake water.

The method of estimation of soluble inorganic phosphorus was after Strickland and Parson (1968) (56), the sensitive range of which lies above 3 µgP/litre. Lake water collected from different parts of the lake during June 1977 when analyzed by above method failed to detect any phosphorus. This indicates that soluble inorganic phosphorus level might be below 3 µg/litre of lake water.

Dissolved organic phosphorus comprises a significant fraction of the total phosphorus present in natural waters. In

one eutrophic lake of Michigan dissolved organic phosphorus plus polyphosphate levels measured, were 70 μgPO_4/litre, in contrast to inorganic orthophosphate concentration of 5-10 μgPO_4/litre (32). In the light of the above work in Lake Michigan it is probable that organic phosphorus which unfortunately could not be determined due to certain experimental constraints, may also be present in the lake Chilka in a higher proportion.

It is also possible that in the lake Chilka inorganic phosphorus level might have decreased during the month of June 1977, below the detection limit due to its consumption by algae and other macrophytes. The above proposition is supported by Rigler (1954) (46) and Kuensler et al (1963) (33), who have also reported that inorganic phosphorus falls below the detection limit during maximal algal growth. Therefore the utilisation of dissolved organic phosphorus may be of great importance, particularly during periods when inorganic phosphorus levels may become low enough to limit algal growth (8-12). The exact extent of limitations of productivity by phosphorus alone or phosphorus and nitrogen together in the lake Chilka remains unknown. This problem probably may be resolved by adding nitrogen and phosphorus to some specifically selected and well protected parts of the lake. A thorough study of seasonal variation of nutrients and primary production of the lake should be made before reachi sion.

Salinity of the lake.

Salinity of the lake water measured from surface samples indicate that the northern region of the lake has the lowest salinity (10.2‰ - 11.2‰) (Table-6). This is perhaps due to constant addition of sewage from the river Daya at this region. The high salinity (17.8‰ - 28‰) recorded in the middle part of the lake is probably due to influx of sea water from the outer channel to this region of the lake. The increased gradient of distribution of salinity towards the mouth of the lake supports the above proposition. However a study of the gradient of salinity in the outer channel itself has not been possible because of constraints in communication to the outer channel, as the entrance to it near Nagarmukh is very shallow and only can be approached during the rains. The southern part of the lake has the lower salinity (16‰ - 16.8‰) than the middle part, because of the lack of thorough mixing of water of the southern part with rest of the lake. It also lacks communication with the sea which keeps the southern part of the lake at lower and uniform salinity level (Fig-3).

Annadale and Kemp (1915) (1) have observed a notable change in the salinity of the lake, in Rambha Bay of the lake during the month of July. Salinity of the lake in the month of July was higher than any other month of the year, which indicated

a considerable influx of salt water from the sea into the lake. Ramanandan et al (1964) measured the salinity of lake Chilka in different seasons and observed that in October the entire water of the lake was almost fresh. The salinity variations in the lake were mainly influenced by flood waters of the Daya river during the above month. In February the salinity was higher than in October which indicated that flood water had stopped coming into the lake. The influx of sea water through the mouth of the lake had also begun in this month. During May the salinity was maximum in the whole lake. However, the rise in salinity was not much in Rambha bay. This was due to restricted nature of this area as it was surrounded by islands and also it was far away from the lake mouth. In this month the main area of the lake was distinctly brackish and the outer channel was actually filled with sea water.

It is probable that the salinity is affected to a large extent by flood water in monsoon season. The rivers of Mahanadi complex bring to the lake by far the greater part of fresh water, that affect the salinity. An important factor of local changes in salinity is the direction of the wind. Tides might be affecting the salinity of the lake, particularly in lean seasons. In a lagoon of the size and shallowness of the Chilka lake, eva-

poration must, especially in tropical climate, be more than considerable and doubtless might be playing a great part in salinity level of the lake.

Salinity and primary production.

Salinity has some effects on productivity rates of individual species (5, 10) but the variations in salinity in the sea are so small that this factor probably may not be important in oceanic productivity. However, the variation in salinity in the lake Chilka is relatively much more than in the sea. Therefore it makes it possible to study the effect of salinity on the primary productivity in a natural ecosystem. The productivity in the lake is highest in the northern part of the lake where the salinity recorded is lowest (Table-12). In the southern part of the lake the productivity is lower than the northern part of the lake while salinity is correspondingly higher. In the middle of the lake the productivity is lowest, while the salinity recorded is highest. Therefore salinity is negatively correlated with productivity in lake Chilka (coefficient of correlation = -0.8666).

However, the productivity also positively correlated with NO_2^- and NO_3^- present in water. Therefore it is difficult to determine the extent of effects of salinity on photosynthesis of phytoplanktons. The study of seasonal variations of salinity, nutrients and productivity is likely to help in the understanding of relationship of productivity with salinity

and nutrients, in this natural ecosystem. Howevery the study of species distribution and their photosyntheth responses to environmental factors like salinity and nutrients at different parts of the lake must be done before coming to any kind of conclusion.

Dissolved oxygen in the lake.

Of all the chemical substances present in natural waters, oxygen is one of the most significant. It is significant both as regulator of metabolic processes of community and organisms and as an indicator of lake conditions. The rate at which atmospheric oxygen passes across the air-water interface and becomes dissolved in the water is dependent upon a number of factors. Increased wave action or other disturbances at the lake surface results in greater passage of gas into solution (26).

Oxygen in natural water may also be derived from photosynthetic activity, of higher plants and photoplanktons. In the lake Chilka the southern parts contain 6.7 to 7.5 mg dissolved O_2/litre, which is higher than the middle of the lake. In the latter part of the lake, dissolved oxygen content is relatively lower, except stretches of Malaban. The net photosynthesis by phytoplanktons is also relatively low in this area.

In the northern part of the lake the oxygen concentration is very high and attends high saturation. This is because of highest net photosynthesis in this part of the lake by photoplanktons.

Overall the oxygen concentration in the lake is related to the net photosynthesis by phytoplanktons and aquatic macrophytes. Since the wave action in the lake has not been quantitised, it has not been possible to correlate it with dissolved O_2.

Study of depth profile of distribution of dissolved oxygen and nutrients in the lake.

Study of depth profile of distribution of dissolved substances have not been done at all the stations of the lake. Three easily accessible places of the lake have been chosen to study it due to lack of time and resources. Table-11 shows that NO_2^-, NO_3^-, and dissolved oxygen are evenly distributed throughout the depth profile of water column at all the three stations. Wind action and consequent wave action is appreciably high in the lake and this leads to a thorough vertical mixing of lake water resulting in almost uniform distribution of soluble components. It may be concluded that there may not be any vertical stratification in the lake.

Trace metals in the lake.

The trace elements are conventionally considered to be those which exist at concentration of 1 mg/kg or less (5, 6).

Iron: Of different trace elements iron is of particular interest because of its importance as a vital element in respiratory and photosynthetic processes of plants and animals.

and because of its part in many chemical reactions in water. Iron is found widely in nature, usually as either bivalent Fe^{++} or trivalent Fe^{+++}. The bivalent ferrous state is soluble, but only under an-aerobic conditions. In the presence of oxygen the trivalent ferric form is present as a colloidal complex in combination with other inorganic ions (55).

Iron concentration appears higher in the northern part of the lake (Table-8) andrelatively lower in other portions of the lake. The higher iron concentration present in the northern part of the lake may be attributed to their influx through the sewage of the River Daya. In other parts of the lake distribution of iron is more or less homogeneous.

Zinc: Zinc is an important essential trace element for plant and animal growth both in terrestrial and aquatic ecosystems. The concentration of zinc in sea water ranges from 1-50 ug/litre, the mean value being close to 3 ug/litre (17).

Zinc concentration in the lake Chilka (Table-9) ranges from 0.02 PPM to 0.19 PPM. The distribution of zinc is highest in the southern parts of the lake, comparatively lower in the northern part of the lake and lowest in the middle of the lake. Thus the distribution pattern of zinc appears to be different from that of iron and the above kind of distribution of zinc remains unexplained.

Copper: Copper is an important trace element for biological system and occure in traces in aquatic environment. Copper is present in sea water at a level of 1.0 ug/litre (17). In high concentration, it is toxic to marine organisms. At normal oceanic concentrations no such toxicity is of course observed.

In the lake Chilka Cu is having uniform distribution at different parts of lake, which ranges from 0.02 PPM to 0.04 PPM (Table-10). Only a higher concentration of Cu is found at the stretches of Balugaon and Nalaban (0.04 PPM).

Trace elements and biological productivity.

The question, "How much iron and other trace elements are available for algal uptake" is difficult to answer. Hulbert and Rodman (1963) (24) have suggested that the sporadic blooms of neritic species in the open sea may be occasioned by the temporary presence of larger quantities of iron. However, there are reports contrary to the above proposition (36).

In the lake Chilka, iron content is higher in northern part of the lake, where productivity is also higher and reverse is the case in rest part of the lake (Table-12). This suggests a positive correlation of primary production with iron content of water (correlation coefficient = +0.6433). However, since in the middle and southern part of the lake nitrogen and other factors are also limiting, it is difficult to predict if iron

is also limiting or not. Since in this lake the iron content is not very low, limitations of primary production by iron appears unlikely. However, the availability of iron to the biological system has not been studied and therefore no definite conclusion can be made.

The concentration of zinc in the lake is considerably too high to limit phytoplankton growth. However, it will be premature to conclude and confirm the above statement since the availability of zinc to the plant growth in the lake is not known.

Since only traces of Cu can sustain plant and animal lives the presence of 0.02 PPM to 0.04 PPM of Cu in the lake may not limit phytoplankton productivity.

Production by macrophytes.

Standing crop measured in the month of June 1977 may not represent the annual primary production of macrophytes, since the season of their peak production in the lake is not known. On the basis of standing crop measured in the month of June 1977, the productivity by Halophila ovata is the lowest and that of Phragmites is the highest (Table-13). The above observations is in accordance with the previous reports (60) that primary production of emergent plants are higher than that of submerged plants.

The daily rate of net primary production of two aquatic weeds of Halophila and Potamogeton measured in the month of June is 0.556 g dry weight/m^2/day and 2.03 g dry weight/m^2/day, respectively (Table-14). The crop growth rate of Halophila appears to be very low as compared with the reported range of primary production by macrophytes (2-10 g dry weight/m^2/day) (60). However, the above values cannot be taken as representative daily net production of macrophytes on annual basis since the monthly variations of biomass have not been taken into account.

Chemical ecology of macrophytes.

The occurence and luxuriance of the various species of higher plants in lakes is regulated to a considerable extent by nutrient and trace elements. The inter-relations of such factors in nature are very complicated.

Nitrogen and phosphorus content of macrophytes.

In the lake Chilka among angiospermic species Halophila ovata and Potamogeton pectinatus are submerged types and Phragmites Karka is emergent one. The red alga Gracilaria is also a submerged type of macrophyte.

Gerloff and Krombholz (1966) (16) have observed that for a submerged plant Vallisneria americana the critical content of nitrogen is 1.3% N and for phosphorus 0.15% P. Among the angio-

spermic plants Phragmites Karka has lowest nitrogen content (1.50%) and Potamogeton has the highest (1.95%). The red alga Gracilaria has 1.70% nitrogen(Table-16). Thus nitrogen in Phragmites Karka is slightly above the critical value (1.3%) reported by Gerloff and Krombholz (1966) (16), although in the northern part of the lake where the above plant grows luxuriantly it is not limiting in water as mentioned in Table-6. On the other hand Potamogeton which grows luxuriantly in the middle part of the lake, (which is deficient in nitrogen) contains highest amount of nitrogen i.e. 1.95%. The red alga Gracilaria contains 1.70% N which is almost equivalent to that of Halophila ovata which contains 1.69% N.

From the above observations it is likely that nitrogen may not be limiting for the growth of emergent reed Phragmites Karka in the lake. The applicability of critical value of nitrogen content derived by Gerloff and Krombholz (1966) (16) for submerged water plants in studying emergent species like Phragmites Karka with greater amount of non-nitrogenous supporting tissue may not be valid.

The emergent plant Phragmites Karka also contains lowest amount of phosphorus i.e. 0.06% which is even less than half of critical amount (0.13%) determined by Gerloff and Krombholz (16) for angiospermic submerged aquatic macrophytes (Table-17).

However, rest of the submerged macrophytes studied have P content above critical value, except the red alga Gracilaria which approaches the critical level having 0.135% P. As phosphorus in water is below the sensitivity limit of the procedure followed, it is not possible to study the limitations of macrophytes by phosphorus. Besides nitrogen and phosphorus contents of sediments have also not been studied. The ratio of mean nitrogen to mean phosphorus content of the macrophytes range from 7.2 to 25.0 (Table-18). Phragmites due to its very low P content has the highest value of N:P (25.0).

The K, Ca, Mg, Fe and Mn contents of aquatic macrophytes.

The above elements (as evident from tables 19 and 20) are lowest in Phragmites Karka (the emergent reed) and highest in the submerged plant Halophila ovata among the angiospermic plants.

A very high content (12.2%) of potassium has been recorded from the red alga Gracilaria. High potassium content for marine alga Sargassum ilicifolium (5.73 - 7.63%) and for Ulva lactuca (3.83%) and for a halophytic plant Acanthus ilicifolius leaves (2.81%) have been reported by Joshi (1976) (28) and Joshi and Gowda (1975) (29). The exact nature of potassium uptake and its relation with other metabolic processes of red alga Gracilaria needs further investigations.

Magnesium content of aquatic angiosperms is higher than the red alga Gracilaria. The level of magnesium is fairly higher than the level of calcium in contrast to fresh water macrophytes where the situation is quite reverse. The Ca:Mg ratio of macrophytes investigated in the lake ranges from 0.140 to 0.491. On the other hand in fresh water plants the above ratio ranges from 4 to 6 (25). Low calcium and high magnesium contents for marine algae Sargassum ilicifolium and Ulva lactuca have been reported by Joshi (1976) (28). Thus a low calcium content in plants investigated (Table-19) growing in saline conditions may be due to low rate of absorption of Ca in presence of other salts.

Iron and manganese are available to water plants in reduced lake sediments. The iron and manganese contents (Table-20) of emergent reed Phragmites Karka are very low but Mn:Fe ratio is high. In other macrophytes Fe and Mn contents are relatively higher, but Mn:Fe ratio is relatively lower. In all samples analysed Mn:Fe ratio was found to be much lower than unity. The above observations are in conformity with previous observation (25) that in water plants iron is somewhat in excess of manganese as is ordinarily the case in inorganic materials of lithosphere. On the other hand Mn:Fe ratio is quite higher in land plants (Average 4.5 in Bowen's observations) (3). The series of emergent

juncifora plants studied by Mayer and Gorham (1951) (41) have a higher Mn:Fe ratio (2.56) than do submerged and floating leaved plants, and in this respect more like land plants. However in the present investigation the emergent reed Phragmites although possess high Mn:Fe ratio (0.433), among the aquatic macrophytes analysed; it falls far below the values observed (41) for emergent plants.

SUMMARY

The lake Chilka is situated in the east coast of Indian Peninsula. The area of the lake is 350 square miles and the maximum depth recorded in the month of June 1977 is 2.75 metres. The lake water is brackish and the lake is connected with theesea by an outer channel. The lake possesses a number of islands in its water body, the Nalaban being the largest island (8 square miles).

The net primary productivity by phytoplanktons of northern part of the lake is highest (262.6 mgC/m^2/hour). The same for the southern part and middle part of the lake is 31.8 mgC/m^2/hour and 14.95 mgC/m^2/hour respectively. The high productivity at the northern part of the lake is probably due to higher levels of nitrogen and low salinity. The higher level dissolved oxygen in this region corresponds to high productivity. The total primary production by the phytoplanktons of the lake is nearly 768675 KgC/day measured in the month of June 1977. The average primary production of the lake is 1.14 gC/m^2/day. Though a wide spread variation in the productivity of the lake does exist, the lake can be broadly divided into the northern eutrophic and southern mesotrophic region.

The nitrogen level (NO_3^- + NO^-_2) in the northern part of the lake is highest ranging from 109.0 to 275.0 ugN/litre. The nitrogen at the southern part of the lake is lower and ranges from 75.0 to 95.0 ugN/litre, whereas same at the middle part of the lake is lowest ranging from 8 ugN/litre to 18 ugN/litre.

The salinity of the lake ranges from 10.2% at the northern part to 35% at the mouth of the lake, where it is connected with the sea. The lowest salinity recorded is in the northern part of the lake, ranging from 10.2% to 11.6%. The higher salinity recorded at the southern part of the lake ranges from 16% to 16.8%. The highest salinity found to be in the middle part of the lake ranging from 17.6% to 28%.

The phosphorus content of the lake is below the sensitivity limit of the method followed. The iron content of the lake ranges from 0.12 to 0.32 PPM. It is quite variable at different stations. However, a higher iron concentration was recorded from Kalupara, Balugaon, Malaban, mouth of the River Daya and island complex of Sanakuda, Badakuda and Samal, located in the southern part of the lake.

The zinc concentration in the lake ranges from 0.025 to 0.19 PPM. The higher levels of zinc occur in the southern part of the lake.

The copper content of the lake ranges from 0.02 to 0.04 PPM. The copper concentration is almost uniform in the lake.

Oxygen concentration of the lake ranges from 6.0 to 9.2 mgO_2/l. The northern part of the lake contains highest amount of oxygen (8.0 - 9.2 mgO_2/litre). The level of dissolved oxygen in the southern part of the lake is relatively lower (6.6 - 7.5

mgO_2/litre), whereas the same for the middle part is lowest (6.0 - 6.8) except at the stretches of Kalahan.

The standing crop of macrophytes measure in the month of June 1977 ranges from 50 to 150 g dry weight/m^2 of land area for the submerged plant Halophila ovata, 650-750 g dry weight/m^2 of land area for emergent reed Phragmites karka and 132-480 g dry weight/m^2 of land area for the submerged red algea Gracilaria. The rate of net primary production in the month of June 1977 is 0.556 g dry weight/m^2/day for Halophila and 2.03 g dry weight/m^2/day for Potamogeton.

For all the constituents of angiospermic plants analysed i.e. N, P, K, Ca, Mg, Fe and Mn the emergent reed Phragmites karka is lowest and except for nitrogen, and the submerged plant Halophila ovata is highest. The submerged plant Potamogeton pectinatus contains highest amount of nitrogen. Among the aquatic macrophytes N:P ratio ranges from 7.2 to 25, Ca:Mg ratio ranges from 0.140 to 0.491, whereas Mn:Fe ratio ranges from 0.028 to 0.455.

CONCLUSION

Primary production studies of the lake reveals that the productivity is dependent upon salinity and nitrogen level of water. The phosphorus content of water was too low to be detected by the method followed. However, in order to definitely establish the extent of limitations of primary production by the nutrients, it is desirable to selectively add above nutrients into some protected parts of the lake water (to prevent mixing of water with rest part of the lake). The study of primary production of above water may be able to establish its extent of limitation by the nutrients in the lake.

Salinity of lake water has been found to be negatively correlated with productivity of the lake. However, as discussed above, nitrogen level of lake water is positively correlated with productivity. Therefore, it is difficult to determine the extent of effect of salinity on photosynthesis of phytoplanktons. The studies on seasonal variations of salinity, nutrients and productivity are likely to help in the understanding of the relationship existing between them.

The northern part of the lake is very shallow. This may be due to heavy eutrophication caused by higher rate of primary productivity in this region both by phytoplanktons and aquatic

macrophytes. The silts brought into the lake by the River Daya falling at this region of the lake may also be partly responsible for its shallowness.

The biomass of macrophytes measured in the lake only represents their standing crop and for an understanding of their annual net production a thorough study of seasonal variation in biomass production should be made. In this study, an attempt has been made to identify Gracilaria beds in the lake. The above alga is important for agar agar production. The lake Chilka provides ample opportunity to study the environmental factors affecting Gracilaria production in a natural ecosystem. Further studies on primary production by Gracilaria can be made to visualise if one agar manufacturing plant can be established near the lake Chilka.

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Fig. 2: Map of the lake Chilka showing positions of different stations and substations. Gross productivity by microphytes (ugC/l/hr.) and standing crop of macrophytes (g dry wt./m^2) during June 1977 have been denoted beside respective station and substation.

(○) Productivity by microphytes.

(□) Standing crop of Halophila ovata.

(●) Standing crop of Potamogeton pectinatus.

(△) Standing crop of Phragmites karka.

(▲) Standing crop of Gracilaria.

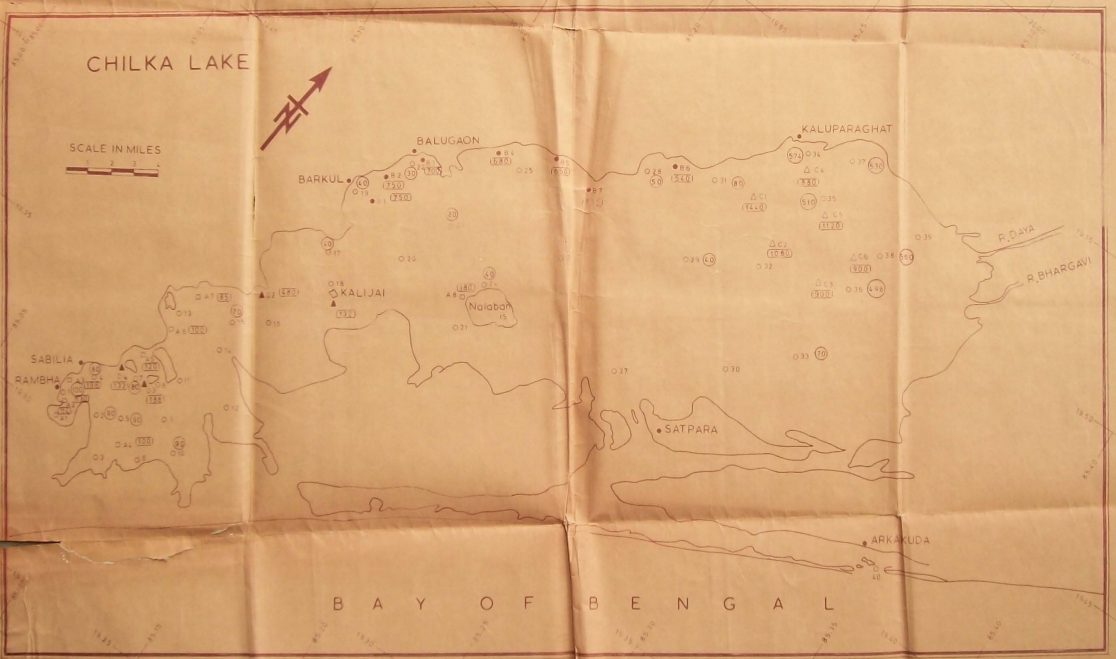
CHILKA LAKE
SCALE IN MILES
BALUGAON
BARKUL
KALUPARAGHAT
KALIJAI
Nalaban
SABILIA
RAMBHA
SATPARA
ARKAKUDA
R. DAYA
R. BHARGAVI
BAY OF BENGAL

FIG. 2

Fig. 3: Map of lake Chilka denoting the salinity level (‰) at different stations of the lake.

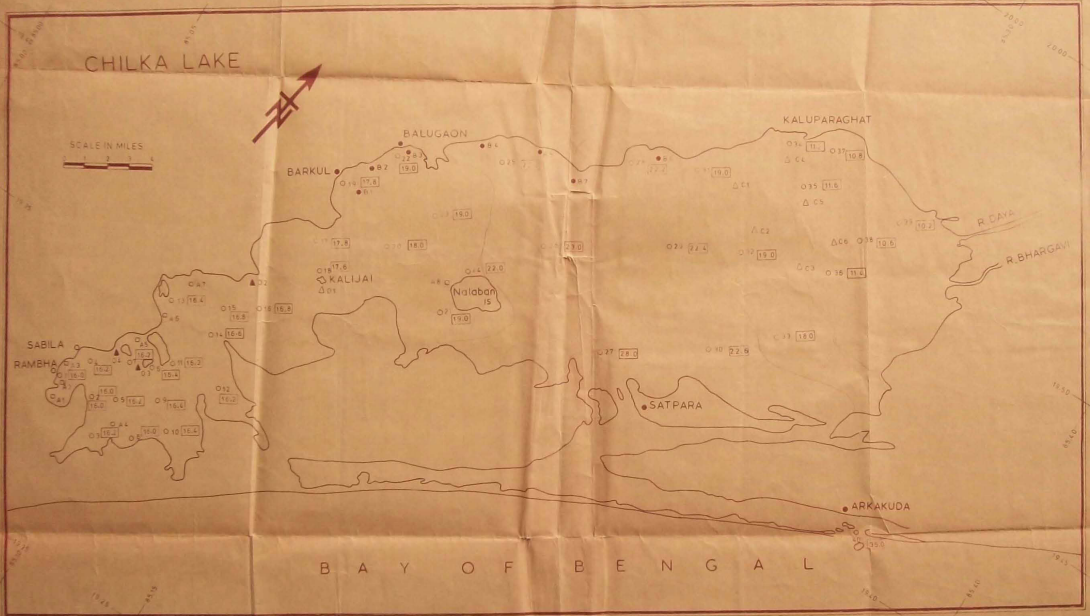
CHILKA LAKE
SCALE IN MILES
BALUGAON
BARKUL
KALUPARAGHAT
R. DAYA
R. BHARGAVI
KALIJAI
Nalaban
SABILA
RAMBHA
SATPARA
ARAKUDA
BAY OF BENGAL

FIG. 3