PRIMARY PRODUCTIVITY DYNAMICS IN THE WINAM GULF OF LAKE VICTORIA

BY

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DECLARATION:

THIS THESIS IS MY ORIGINAL WORK AND HAS NOT BEEN PRESENTED FOR A DEGREE IN ANY OTHER UNIVERSITY.

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THIS THESIS HAS BEEN SUBMITTED FOR EXAMINATION WITH MY APPROVAL AS UNIVERSITY SUPERVISOR.

4 April, 1989

PROFESSOR S. G. NJUGUNA

SUPERVISOR

DEDICATED TO MY WIFE MORAA AND

CHILDREN, KATHURE, MOKAMI AND MURUGI

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ABSTRACT

Primary productivity in the Winam Gulf and the various factors that are likely to influence it were studied from February, 1986 to May, 1987. Surface water temperature varied little among the five sampling stations established in the Gulf. However, slightly lower temperatures were encountered at Nyakach Bay, which was attributed to the influence of colder water from Rivers Nyando and Sondu. Surface water temperature ranged between 25.7 ± 0.4 ^{o}C to 27.6 ± 1.0 ^{o}C. Temperature varied by 3.5 ^{o}C during a 24-h period at Nyakach Bay on 29 and 30 December, 1986. Solar radiation influenced water temperature to a great extent with values rising during periods of high insolation and vice-versa. The water column was generally thermally uniform with differences between surface and bottom temperatures not exceeding 0.8 ^{o}C.

Concentration of dissolved oxygen ranged between 8.0 ± 0.6 and 8.5 ± 1.0 mg l^{-1}. The highest value measured was 11.1 mg l^{-1} at Nyakach Bay in July, 1986. Concentrations were usually higher near the surface than at greater depths. On a diel basis, concentrations reached maximum levels at 1500 h which coincided with highest productivity values.

Secchi disc visibility varied seasonally ranging from 0.2 to 1.4 m and having an inverse relationship to chlorophyll a (r= - 0.695). The penetration of the photosynthetically active radiation (PAR) declined with increasing depth and recorded the lowest value at Nyakach Bay where highest chlorophyll a, productivity and turbidity values were reached. Water pH ranged between 7.5 to 9.0 during the period of this study. Maximum conductivity of 145 µS cm $^{-1}$ was recorded at Nyakach Bay. Alkalinity of the Gulf ranged between 52 and 77 mg $CaCO_3$ + HCO_3 l^{-1}. Both conductivity and alkalinity rose during the dry season and dropped during the wet season.

Phytoplankton species and biomass remained generally uniformly distributed in the water column. The blue-green alga, Microcytis aeruginosa Kutzing. was the most dominant phytoplankton species in the Gulf, its highest biomass being 150 mg m $^{-3}$. Its biomass together with that of Anabaena sp., the next most important blue-green alga, reached maximum during the rainy season. Nitzschia sp. was the most important diatom in the Gulf, followed by Melosira sp.

Chlorophyll a concentration reached a maximum level of 50 µg l^{-1} at Nyakach Bay in may, 1986 when the highest phytoplankton volumes were recorded. Two peaks of chlorophyll a concentrations were encountered, a major one during May to June and a minor one during October to January. Concentrations of chlorophyll a were lower at the surface than just below the surface.

Concentrations of nutrients (PO_4 - P and NO_3 - N) were higher in the shallow enclosed bays, notably Nyakach Bay and Kisumu Bay and rose during the rainy season. A high concentration (34 µg PO_4 - P l^{-1}) was recorded at Nyakach Bay in May, 1987 while the lowest (2 µg PO_4 - P l^{-1}) was recorded at Kisumu Bay in February, 1986. Similarly a maximum NO_3 - N concentration of 85 ug l^{-1} was recorded at Nyakach Bay in February, 1986 and the minimum (2.5 µg l^{-1}) at Kisumu Bay in February, 1986. The water column exhibited a more marked stratification of NO_3 - N than PO_4 - P at the relatively deeper Ndere Island Station.

A high photosynthetic rate of 1.2 g O_2 m^{-3} h^{-1} was recorded at Nyakach Bay in January, 1987. This value was nearly double the highest (0.65 g O_2 m^{-3} h^{-1}) reported by Talling (1965). During the same period the highest mean productivity in the water column was 0.74 g O_2 m^{-3} h^{-1}. Two peaks of productivity were encountered, one during June to August and another one during November to February. In the water column productivity declined with increasing depth as did water transparency. Productivity was positively correlated with nutrients, particularly PO_4 - P (r = 0.913) and chlorophyll a (r = 0.873).

CHAPTER 1

INTRODUCTION

1.1 GENERAL

In all ecosystems, plants are the basis of all energy needed by the organisms. This is due to their ability to make organic compounds using inorganic raw materials, i.e., carbon dioxide, water, nutrients and trace metals through the process of photosynthesis. On land, higher plants are the major producers. In aquatic ecosystems, phytoplankton are of great importance because they comprise the major portion of primary producers both in the sea and in fresh waters. They are, like the higher plants on land, the basic food for all consumers such as zooplankton and fish, which subsequently is utilised by man (Zeitschel, 1978). It is for this reason, therefore, that their ecology and biology are crucial aspects to be understood in making any sound management policies in the exploitation of water masses whether natural or man-made.

Besides their importance as producers, phytoplankton may be used to identify " natural regions" of the oceans. These are characterized by typical species or groups of species. Worldwide to-date, most work in biogeography in the sea has been carried out with zooplankton (McGowan, 1971; Zeitschel, 1978) but there are now indications that phytoplankton are also good indicators of " natural regions" as defined by latitude e.g. boreal, subtropical, and some oceanographic features such as ocean gyres (Braarud et al. 1953; Smayda, 1958). Phytoplankton normally consists of a heterogeneous collection of algae and the problems posed by the distribution and seasonal succession of the species present are not only of interest in themselves, but such quantitative differences may have effects on the higher components of the food chain and are thus of great economic importance (Sournia, 1978).

Most African lakes have pronounced seasonal fluctuations in phytoplankton abundance and photosynthetic rates. These fluctuations usually correspond to seasonal weather changes that alter physico-chemical factors such as river inflows, vertical mixing, turbidity, temperature and presumably the availability of nutrients and light (Symoens et al. 1981). Lake Victoria is among the lakes with such distinct seasonal variations (Talling, 1965, 1966).

Seasonal variations in the abundance of phytoplankton species are an important and familiar feature of African lakes (Symoens et al. 1981). In all aquatic ecosystems, the structure of the photosynthetic populations is a dynamic one and is constantly changing in species composition and biomass which may affect photosynthetic rates, assimilation efficiencies, rates of nutrient utilization, grazing rates and so on (Wetzel & Likens, 1979). In order to understand the phytoplankton community structure, it is important to study the population changes especially the variations in spatial and temporal distribution.

Chlorophylls are the key components in plants for trapping light energy in photosynthesis and thus their quantitative determination is of vital importance (Faust & Norris, 1982). In limnological studies, the concentration of chlorophyll a in water is widely used as a measure of the phytoplankton biomass (Desortova, 1981). There has been an increasing use of pigment estimations, particularly of chlorophyll a, for assessing the abundance of planktonic algae (Talling & Driver, 1963). The use of chlorophyll a as an estimate of algal biomass has the advantage of the speed, simplicity and reproducibility associated with its measurements although these are offset by its failure to give any information on population structure (Jones, 1977).

The most important plant pigment is chlorophyll a because it is normally the most abundant in living material. Measurement of chlorophyll a, therefore, becomes important in any phytoplankton productivity and biomass studies.

The availability of chemical nutrients and their temporal variation are usually the principal factors controlling phytoplankton abundance in tropical African lakes and hence the understanding of their supply is crucial to the rational management of water resources (Symoens et al. 1981). Phosphorus (P) and nitrogen (N) compounds are major cellular components of organisms. Their availability may be less than the biological demand and so environmental sources can regulate or limit production of organisms in freshwater (Wetzel & Likens, 1979). It is suggested that in African lakes, very little evidence exists for nutrient limitation other that P and N (Kalff, 1983, Gaudet & Muthuri, 1981).

East African lakes are noted for their high photosynthetic rates and high standing crops of algae (Melack & Kilham, 1974), but very little is known about their nutrient dynamics (Peters & MacIntyre, 1976).

It is a well known fact that increased nutrient loading frequently results in increased phytoplankton standing crop with undesirable blue-green algal species becoming the dominant populations (Pieterse & Toerien, 1978), a phenomenon that is likely to occur in lakes surrounded by agricultural areas.

In various parts of the world, the decrease in the supply of phosphate-phosphorus to the aquatic environment has been suggested as a long-term solution for the control of eutrophication problems. This approach was used with remarkable success in Lake Washington (Edmondson, 1969). Owing, therefore, to their important role in nourishing and controlling algal production, which in turn affects water quality, chemical nutrients form a crucial aspect of investigation in algal production studies.

To-date, most of the information available on Lake Victoria's primary productivity and related factors has been based on studies carried out in the open lake and little has been done in the Winam Gulf. Most of the past investigations have been carried out in the deep offshore waters of the open lake. These include such very early studies by Worthington (1930) and Bachmann (1933).

Indeed, until recently when Melack (1976a & b; 1979a b) did some studies in the Gulf, the only limnological investigations had been those by Worthington (1930) and Talling (1965), which were only brief visits to the western end of the Gulf.

Talling (1966) studied various aspects of stratification and phytoplankton growth in the open Lake Victoria, but visited the Winam Gulf only once, in December, 1960. Melack, (1979a) measured changes in phytoplankton photosynthetic rates, underwater light and temperature in four Kenyan lakes, Lake Naivasha, Crescent Island Crater, Oloiden and the Winam Gulf. In the Winam Gulf, the measurements were made over a period of only five months in 1973.

Since the study by Melack (1979a & b), no comprehensive study has been carried out to assess the status of the primary productivity and related aspects in the Gulf. Furthermore, there has been a lack of limnological data collected over a long period of time e.g. one year, to adequately assess seasonality. In a more recent study, Foxall et al. (1985) measured concentrations of nutrients, chlorophyll a and determined levels of other physico-chemical factors.

1.2 LITERATURE REVIEW

Data on physico-chemical factors in Lake Victoria are available from such early works as that of Graham (1929) and Worthington (1930). Both these workers measured a pH of 9.0 in off-shore stations of the main Lake Victoria. They made the first observations on changes of thermal stratification. Worthington (1930) concluded that the central open waters of the lake were permanently stratified but only with a small temperature gradient and lacking a marked discontinuity or thermocline. Fish (1957) found thermal stratification either absent or extremely slight from mid-June to mid-August but present in March to mid-May when a discontinuity layer was present within the 40 - 60 m depth range.

Later, Talling (1957) studied stratification of temperature and oxygen in deep off-shore stations of the main lake (Z_m = 65 m).

Talling (1966) found variation of pH to have a parallelism with that of dissolved oxygen, its changes being determined primarily by alterations in the content of dissolved carbon dioxide either by photosynthetic removal in the 0 - 20 m stratum or by accumulation in the lower layers following organic decomposition.

During much of the year, the upper half of the water column showed a pH of 8.0 ± 0.1 with a decline to a minimum of 7.0 below the deep thermal discontinuity. Alkalinity was 0.92 ± 0.02 m.eq. l^{-1}. Phosphate and dissolved silicon showed higher concentrations near the mud surface and lower concentrations in the uppermost 20 m. High concentrations (above 20 ug $PO_4 - P$ and $NO_3 - N$ l^{-1} and above 5 mg SiO_3 l^{-1}) occurred at depths less than 40 m during periods of the weak thermal stratification.

In a recent study of the Gulf, Melack (1979a & b) reported that the whole water column was well oxygenated during periods of mixing. Maximum oxygen concentrations recorded in the Gulf during the period 1973 - 1974 were between 6.5 and 7.7 ug l^{-1}.

The seasonal variation of phytoplankton distribution and biomass have been studied in various parts of the world including lakes in East Africa. A study in Lake George, in Uganda, showed that the horizontal distribution of certain phytoplankton species could be attributed to the movements of the water mass and could be correlated with the grazing effects by fish populations which showed similar patterns of distribution (Burgis et al. 1973). Similar studies conducted in fish ponds have shown that phytoplankton quantities increased gradually at the onset of the rainy season (Imevbore et al. 1972).

Phytoplankton spatial variation has been studied in more detail in the main Lake Victoria than in the Winam Gulf. The first records of the vertical distribution of phytoplankton were given by Worthington (1930) and later by Bachmann (1933). Ross (1955) made a qualitative analysis of the common algae in Lake Victoria while Fish (1957) studied the distribution of the diatoms, Melosira and Nitszchia spp. The diatoms Melosira nyassensis Kutzing. var. victoriae was the most dominant and was found to occur in the lower layers of water and around the thermal discontinuity. Peaks were found to occur at the end of the isothermal mixing periods and to decline upon development of stronger thermal stratification.

Talling (1957) reported maxima of the blue-green algae Lyngbya sp. and Aphanocapsa sp. at 0 - 20 m depths with their numbers diminishing greatly at depths of 50 - 60 m. Counts of the dominant diatom, M. nyassensis var. victoriae yielded 80 individuals per millilitre of the lake water. The unicellular diatoms, Cyclotella and Nitzschia spp. were found to dominate the middle water layers.

In another study, Talling (1966) reported seasonal variations in phytoplankton species and biomass in the open Lake Victoria. According to him, the lake has general characteristics of a great variety of species and a dominance of small coccoids Myxophycea.

It was shown that the blue-green algae were replaced by the diatoms in dominance during July and August. During August and September deep maxima of M. nyassensis var. victoriae, with Stephanodiscus sp. were observed toward the centre of the lake and a maximum of Anabaena flos-aquae Brebisson in the 0 - 30 m layer during the month of December, 1960. Melack (1979b) found phytoplankton peaks in the Winam Gulf to occur in October.

Much of the available information on phytoplankton pigment in Lake Victoria is based on the deep off-shore stations sampled in the main lake. Among the studies conducted in this area was that by Talling (1966). Chlorophyll a concentration was found to decline with depth over the larger part of the water column although appreciable quantities were usually found at the bottom. A maximum concentration was found to exist in the 0 - 20 m layer in November and December during which time blue-green algae were predominant in the phytoplankton. The second maximum concentration in August was composed largely of two species of diatoms.

It was shown that phytoplankton sunk to form a deep secondary maximum of chlorophyll a reaching a concentration of 23.4 µg chlorophyll a l^{-1} near the mud. This was the highest value encountered during the 10 months of chlorophyll a measurements in the study. Concentrations measured in the euphotic or photosynthetic zone varied only between 1.2 and 5.5 µg l^{-1}.

In the deep off-shore water of the main Lake Victoria in an earlier study, Talling (1965) reported a value of 44 mg chlorophyll a m^{-2} in 1976 for the Winam Gulf. In a more recent study of the Winam Gulf Njuguna *et al*. (1985) measured chlorophyll a concentration of 13.6 ± 1.7 µg l^{-1}.

Few investigations concerning nutrient concentrations have been conducted in Lake Victoria. Talling & Talling (1965) reported a total phosphorus concentration of 67 µg l^{-1} in March and 140 µg l^{-1} in May 1961 at a depth of 60 m at an offshore station of the main lake. During these investigations PO_4 - P was found to be between 0.2 and 0.6 of the total phosphorus with absolute concentrations being higher in the upper layers of the water column. The nitrate nitrogen (NO_3 - N) concentrations measured in the Winam Gulf in the same study were 15.28 and 29.0 µg l^{-1} in December 1960 and May 1961, respectively.

In a later study, Talling (1966) reported a phosphate-phosphorus value of 13 µg l^{-1}. Faxall *et al*. (1985) measured

27 ± 7 µg l^{-1} total P and 523 ± 96 µg l^{-1} total N in nearshore areas of the Winam Gulf. Silicate, an important nutrient in the growth of diatoms, was measured in the open lake and found to be 4.3 and 5.9 mg l^{-1} in 1960 and 1961, respectively (Talling & Talling, 1965). Concentrations of silicate in the Winam Gulf were found to range between 3 and 9 mg l^{-1} . Variations of total phosphorus, iron and manganese were studied for a short period by Talling (1966). In the same study, concentrations of some major ionic constituents were measured and values obtained were:

Ca = 5.6 mg l^{-1}

Mn = 2.6 mg l^{-1}

K = 3.8 mg l^{-1}

Cl = 3.9 mg l^{-1}

SO_4= 2.3 mg l^{-1}

Na = 10.4 mg l^{-1}

HCO_3 alkalinity = 0.92 m.eq. l^{-1}

Laboratory experiments have previously been conducted to study the growth of Lake Victoria phytoplankton by enriching the water with nutrients. Evans (1961) found that the addition of sulphate did not stimulate phytoplankton growth while addition of 10.7 mg l^{-1} nitrate concentration and small quantities of phosphate increased phytoplankton growth.

As has been stated earlier on, most of the available information about Lake Victoria has been based on the main lake and very little on the Winam Gulf. The works of Melack (1979a & b) have hitherto stood as the only comprehensive study on primary productivity in the Gulf. In this study he found that photosynthetic rates were lower at the surface than just below the surface, a phenomenon attributed to photoinhibition of the photosynthetic reaction, increased phytoplankton sinking and photorespiration.

In his study, the daily gross primary productivity for the Gulf was estimated at 6.2 g O_2 m^{-3} d^{-1} in December 1976. Earlier on, Talling (1965) working in the open lake had reported a value of 7.4 g O_2 m^{-3} d^{-1} in the period 1960 - 1961. The maximum photosynthetic rate recorded by Talling (1965) was 650 mg O_2 m^{-3} h^{-1} at a depth of 1.5 m in October, 1963. The minimum rate was 120 mg O_2 m^{-3} h^{-1} at the surface in August of the same year. The photosynthetic rate per unit chlorophyll $\underline{a}$ at 0.5 m depth was estimated as 12 mg O_2 mg chlorophyll $\underline{a}^{-1}$ h^{-1} while values of offshore subsurface water were 14 - 35 mg O_2 mg chlorophyll $\underline{a}^{-1}$ h^{-1}.

1.3 STUDY OBJECTIVES

From the foregoing account given above (1.2) there is clearly a general lack of up-to-date information on the primary productivity in the Winam Gulf. The present study was designed to endeavour to provide such information. The objectives of the study are:

(I) to measure various physico-chemical factors which are likely to influence primary productivity in the Gulf.

(II) to examine the phytoplankton community in the Gulf and determine its composition by taxonomic groups.

(III) to determine the biomass of the phytoplankton together with chlorophyll *a* content of the Gulf water.

(IV) to measure nutrient (phosphate-phosphorus and nitrate-nitrogen) levels in the Gulf.

(V) to measure the photosynthetic rates of the phytoplankton based on short-term *in situ* incubations of the Gulf water samples.

CHAPTER 2

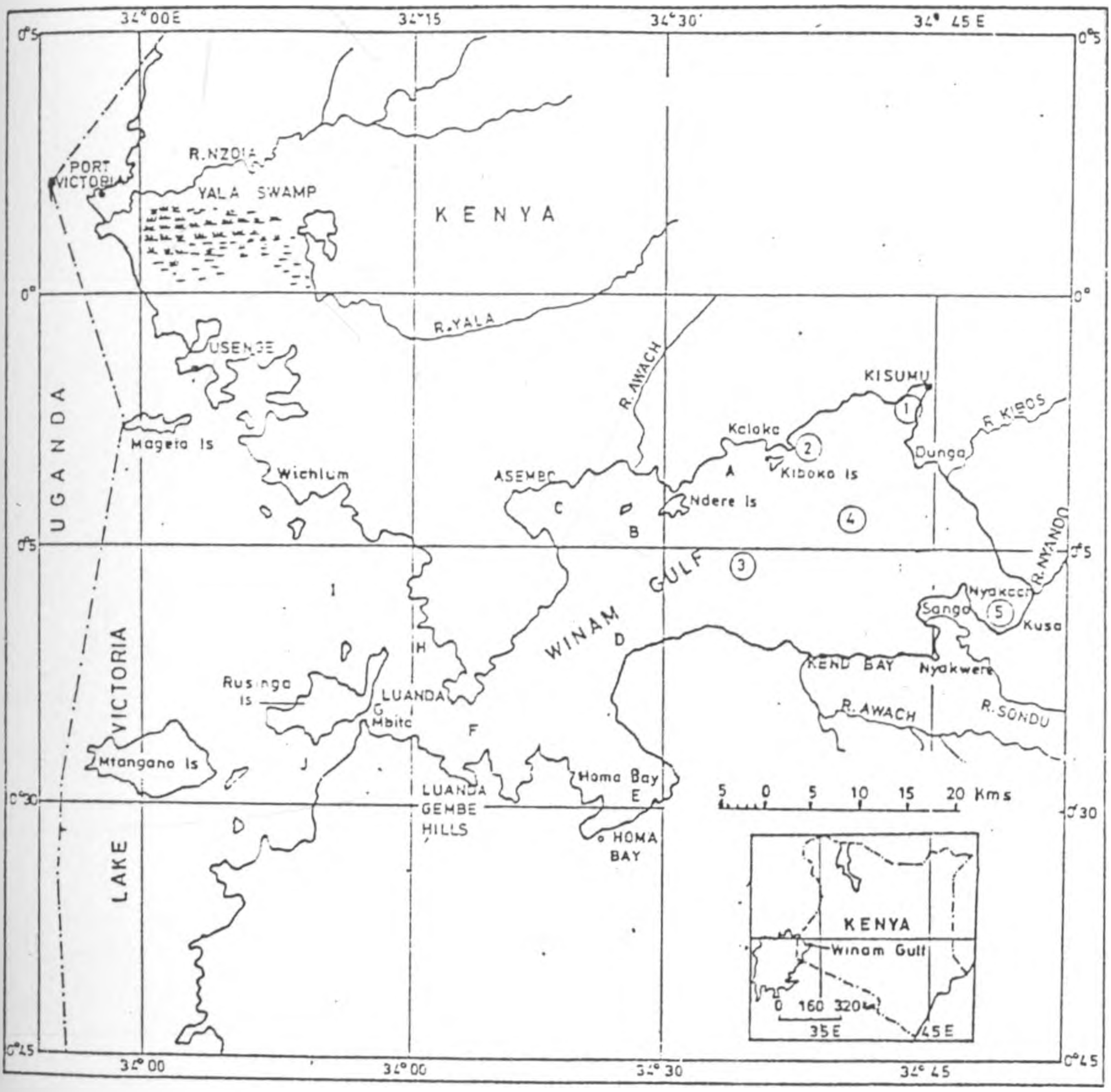
THE STUDY AREA

2.1 GENERAL DESCRIPTION

Lake Victoria, the largest lake in Africa and the world's second largest freshwater lake, is a tectonic lake formed during the Pleistocene period (Kendall, 1979). It is shared by the three East African countries, Kenya, Uganda and Tanzania. It has a total surface area of 69,000 km^2 (Whitehouse & Hunter, 1902). The Kenya portion of Lake Victoria comprises the Winam Gulf (also referred to as the Nyanza or Kavirondo Gulf) and a small part of the main lake. The total surface area of the Kenyan portion of Lake Victoria is 4,000 km^2 which is only 6 % of the lake's surface area. The Winam Gulf has a surface area of 1300 km^2 (Whitehouse & Hunter, 1902).

The Gulf connects with the main lake via the Rusinga Channel south of Uyoma Point and extends to a shallow, indented bay to the port of Kisumu (Fig. 1). Shallow areas of the Gulf are bordered by swamps dominated by <u>Cyperus papyrus</u> L., <u>Typha</u> and <u>Phragmites spp</u>. (see plates 1 & 2). Winam Gulf lies at an altitude of 1146 m above sea level and within latitudes of 0^0 4′ S - 0^0 32′ S.

Fig. 1. Map of the Winam Gulf showing the sampling
Survey of Kenya Map SK D.D.S. (II) series Y
Edition, 1971.


34°00E
34°15
34°30'
34° 45 E
0°5
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0°45
PORT VICTORIA
R.NZOIA
YALA SWAMP
KENYA
R.YALA
USENGE
UGANDA
Mageta Is
Wichlum
ASEMBO
R.AWACH
KISUMU
Kaloka
Kiboko Is
Ndere Is
Dunga
R.KIBOS
R.NYANDO
A
B
C
D
E
F
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I
J
①
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③
④
⑤
WINAM GULF
Nyakach
Sango
Kusa
KENDU BAY
Nyakwere
R.AWACH
R.SONDU
LAKE VICTORIA
Rusinga Is
LUANDA
Mbita
Mfangano Is
LUANDA GEMBE HILLS
Homa Bay
HOMA BAY
5 0 5 10 15 20 Kms
KENYA
Winam Gulf
0 160 320km
35E
45E
34°00
34°00
34°30
34°45

FIG. 1

Plate 1. The southern shore of the Winam Gulf showing swamps dominated by *Cyperus papyrus* L. near the mouth of River Kibos (A) and at Nyakach Bay (B).

Plate 1.

A

B

Plate 2. *Phragmites sp.* at the northern shore of the Winam Gulf near the Fisheries Department at Kisumu (A) and *Typha sp.* at the southern shore near Dunga (B).

Plate 2.

A

B

It lies within longitudes 34^0 15′ E – 34^0 40′ E (Fig. 1). The shoreline is 500 km long. The northern shore is mainly rocky while the southern shore is flat and swampy. The maximum width is 30 km. The Gulf is relatively shallow with a maximum depth of 43 m and a mean depth of 6.8 m (Whitehouse & Hunter, 1902).

Direct rainfall provides over 80% of the total water input the rest coming from rivers and runoff. Rainfall around the Gulf varies from 750 mm in the warmer low-lying areas around the lake shore to well over 1,800 mm per year in the highlands. Rainfall records for Kisumu document a main rainy season in March, April and May with minor pulses of rain in August and again in November. The annual mean rainfall is 1278 mm (Ogalo, 1981).

Three large rivers, the Nyando, Sondu and Awach, which drain the western slopes of the Mau range, provide the major inputs of water besides direct rainfall. The prevailing winds over the Gulf are southwesterly. Imposed on the seasonal fluctuations in the water level, characteristic of many tropical African lakes, are diurnally varying levels caused by wind-induced tilting towards the north-eastern corner in the late afternoon (Melack, 1976).

2.2 THE SAMPLING STATIONS

Five sampling stations were established in the Gulf during the study period (Fig. 1). Their choice was made on the basis of the following considerations:

Station 1: Kisumu Bay

Within the Kisumu Municipality and near the harbour. Considerably shallow enclosed bay influenced by human activity. Swampy northern and eastern shores. Maximum depth = 3.0 m.

Station 2: Kiboko Island

About 18 km west of Kisumu Town. Deeper and more open station with less human influence. A fishing ground. Rocky northern shore. Maximum depth = 3.6 m.

Station 3: Ndere Island

Approximately 30 km west of Kisumu Town and about 3 km from the shore. Rocky northern shore. Deep water (maximum depth = 7 m). An active _Lates_ _niloticus_ (L.) fishing ground.

Station 4: Off Dunga

Approximately 12 km south-west of Kisumu Town and at about 5 km from the shore at Dunga. An active fishing ground. River Kibos, a small stream, enters the lake from the east. A shallow open station.

Maximum depth = 3.2 m.

Station 5: Nyakach Bay

About 23 km south-east of Kisumu Town and 3 km from Sango Village. A shallow bay through which River Nyando enters the Gulf. This station is largely influenced by River Nyando and River Sondu.

Maximum depth = 3.0 m.

In addition to stations 1-5 described above, Stations A to I (Fig. 1) were sampled once for comparative purposes. The latter set of stations was sampled during the initial stage of the sampling programme.

CHAPTER 3

MATERIALS AND METHODS

3.1 THE SAMPLING PROGRAMME

Water samples were collected on a monthly basis over a period of 16 months beginning from February 1986 to May, 1987. No samples were collected in March and April, 1986. In February, 1986 the data collected were aimed at providing a basis for comparison between the five established sampling stations and others (A to I) inside and outside the Winam Gulf (Fig. 1). In subsequent months, only the routine stations (1 to 5) were sampled. Sampling and *in situ* measurements were done at the same time each month working between 0900 and 1500 h local time.

3.2 PHYSICO-CHEMICAL FACTORS

Water temperatures were measured *in situ* with a thermistor attached to a a Fluke 77 multimeter, readable to 0.02 ^{0}C. The thermistor was held by a long cable marked at 0.5 m intervals by which it was lowered down the water column. At each depth of temperature measurement, time was allowed until there was a constant reading which was recorded.

The vertical distribution of dissolved oxygen was measured using a pHOX polarographic electrode which recorded measurements to approximately 0.1 mg l^{-1} dissolved oxygen. Light penetration was estimated with a 20-cm diameter Secchi disc bearing alternate black and white quadrants. Underwater light attenuation of the photosynthetically available radiation (PAR) was measured with a Skye photometer SKP 200 fitted with an SKP 215 quantum sensor.

Alkalinity was determined by titrating 100 ml of the lake water with 0.1 M hydrochloric acid to the bromocresol green end point. Conductivity was measured with a Jenway PCMI conductivity meter corrected to 25 ^{0}C. Air temperatures were measured with a Sierra Misco "Weather Station" Model 1045, an instrument which acts as an anemometer and a thermometer. Water pH was measured simultaneously with dissolved oxygen using the pHOX meter. Turbidity was measured with a portable HACH turbidimeter.

3.3 PHYTOPLANKTON BIOMASS

Lake water samples for microscopic examination and enumeration of phytoplankton were collected using a 2-l van Dorn sampler from specific depths, and an integrating sampler for samples from the surface to a depth of 3 m. Following sample collection, a volume of 100 ml was put in brown glass bottles. The phytoplankton were fixed and preserved with 1 ml of Lugol's solution prepared according to Vollenweider (1974) and whose composition was:

100 g KI dissolved in 1 l distilled water
50 g iodine (crystalline) dissolved in
100 ml glacial acetic acid.

This method of preservation has an advantage in that the bulk of flagellates retain their flagella and also other phytoplankters fix quite well (Vollenweider, 1974). The brownish yellow colour acquired by the cells makes them more easily observable during the counting process. During transportation to the laboratory, the preserved samples were put in an insulated box of ice, allowing them to remain cold but not frozen. Vibrations were avoided as they tend to cause undesired aggregates and cell disintegration (Sournia, 1978).

In addition to the preserved material, samples were collected for examination and counting of living phytoplankton. These were placed in bottles and the bottles in turn were placed in an insulated ice box. In the laboratory, examination and counting of the phytoplankton was done using the Sedgewick-Rafter cell and Utermohl's method under the inverted microscope. Identification of the phytoplankton was done to the genus level and to species level where possible, using various keys and diagrams such as the one prepared by Aldberg et al. (1971). Concentration of phytoplankton cells was done by sedimentation.

A volume of 50 ml of the preserved sample was placed in a narrow glass cylinder and left to stand undisturbed for several hours after which half of this volume was removed by sucking out gently the upper 25 ml of the sample.

Examination under the microscope ascertained that this portion contained no algal cells before it was discarded. The remaining 25 ml concentrated portion of the sample was used for examination and counting. It was well shaken after which an aliquot was used to fill a Sedgewick-Rafter cell. The cell was then examined under the inverted microscope.

The counting on a Sedgewick-Rafter cell has been described by various workers and different recommendations have been given regarding the number of cells to be counted. Littleford _et al_. (1940) demonstrated empirically that 40 fields of the Sedgewick-Rafter cell were adequate when 1,000 or more cells were present. Kutkuhn (1958) determined that 10 fields in each of 4 cells gave most efficient results and McAlice (1971) has recommended the counting of 20 to 30 fields in each of 3 cells. In this study, 25 fields of each of 4 Sedgewick-Rafter cells were counted and the average count for each species taken.

Cell numbers on their own do not give a true picture of the actual biomass (Vollenweider, 1974). More useful information can be obtained from cell counts only after determination of cell volumes (Paasche, 1960; Smayda, 1965). For this reason the number of individuals of each species was multiplied by the average cell volume calculated from the mean dimension of a cell assuming that its form corresponded roughly to simple geometrical solids, e.g.

Sphere : $(4 r^3 \pi)/3$ or $4 r^3$
Cone : $(r^2 \pi h)/3$ or $r^2 h$
Cylinder: $(r^2 \pi h$ or $3r^2 h)$. (Vollenweider, 1974)

Values of volumes obtained for various species were compared with those calculated by Nauwerck (1963, Table 1).

3.4 CHLOROPHYLL *A*

Water samples for the determination of chlorophyll *a* were collected using an opaque plastic van Dorn sampler lowered open to, and closed at, specific desired depths of sampling by a weight or "messenger", or using an integrating sampler when measurements were required for integrated samples. The integrated sampler was a 3 m polyvinyl chloride (PVC) pipe fitted with a plastic plate on one end and a rope attached to the plate and running the whole length of the pipe through the centre. The sampler was lowered vertically into the water column with its lower end open. The bottom end bearing the plate was closed by pulling the rope, thus obtaining the water sample. The capacity of the sampler was 1.8 l.

Table 1. Volumes of some freshwater phytoplankton species calculated by Nauwerck (1963) and Findenegg (unpublished). Source: Vollenweider (1974).

Algal apecies		μ^3
Microcystis aeroginosa	(colony)	100,000
Anabaena flos-aquae	(colony)	80,000
Dinobryon divergens		800
Melosira granulata	(1 mm)	60,000
Melosira islandica	(1 mm)	80,000
Stephanodiscus astraea		2,000
Asterionella formosa		700
Synedra acus angustissima		1,000
Gloecoccus shroeteri	(colony)	5,000
Oocystis solitaria		400
Scenedesmus quadricauda		1,000
Ankistrodesmus falcatus		250
Botryococus braunii	(colony)	10,000
Chlorella vugaris		200
Closterium aciculare		4,000
Rhodomonas lacustris		200
Cryptomonas ovata		2,500
Ceratium hirundinella		70,000

Filtration of water samples to retain phytoplankton was done in the field on the boat soon after sampling. Aliquots of 100 to 200 ml of the lake water were filtered depending on the abundance of algae suspended in the water. Whatman GF/C glass fibre filters (diameter 4.7 cm) were used. These were preferred to membrane filters for their advantages over the latter which are outlined by Holm-Hansen & Reimann (1978) and Marker et al. (1980). All operations were done in subdued light as it has been shown that light has the effect of degrading chlorophyll and its derivatives (Moss, 1968). The filters were held clamped in a suitable support and connected to a hand-operated vacuum pump. A small amount of magnesium carbonate was added to the filter prior to the filtration process to aid retention and as a precaution against development of acidity which could lead to degradation of the extract.

After filtration the filter was removed and rolled up and placed in a test tube which was corked and placed in an insulated box packed with ice blocks ensuring a temperature not higher than 4 ^{0}C. The filters were thus stored in the cold for periods not exceeding 48 hours prior to analysis. In the laboratory, analysis was made following extraction in absolute (99.8%) methanol.

Acetone and methanol are the most widely used extraction solvents for phytoplankton pigment determination (Arvola, 1981). However, acetone extraction is not very efficient with Chlorophyceae and Cyanophyceae (Jones, 1977; Holm-Hansen & Reinmann, 1978).

A volume of 14 ml of absolute methanol was added to each test tube containing the filter. The methanol was boiled over a water bath at approximately 80 ^{0}C for 30 seconds taking precaution to avoid any spurting out. The mouths of the test tubes were covered with cellophane to prohibit loss of methanol through evaporation. The contents of the test tubes were then poured into centrifuge tubes and the filters squeezed thoroughly with a glass rod ensuring complete and even extraction. The tubes were centrifuged for 5 minutes at 2500 rpm using a TECHN S II centrifuge. The extracts were decanted into spectrophotometer cuvettes of 1 cm pathlength and optical density measured against a methanol blank at 665 nm wavelength, the peak of chlorophyll a absorption and at 750 nm wavelength for turbidity correction using a Bausch & Lomb SP 88 specrophotometer.

Chlorophyll a concentrations were calculated from the following equation of Parsons & Strickland (1963):

$$\text{Chl. } \underline{a} \ (\mu g\ l^{-1}) = \frac{13.9 \times A \times v}{d \times V}$$

where 13.9 = specific absorption coefficient for methanol

A = Absorbance at 665 nm minus absorbance at 750 nm

v = Volume of solvent in ml

V = Volume of initial filtered sample in litres

d = cell pathlength in cm

3.5 NUTRIENTS

3.5.1 Phosphate - phosphorus (PO_4 - P)

Determination of phosphate - phosphorus or soluble reactive phosphorus (SRP) was done according to the stannous chloride method (American Public Health Association, 1985). Water samples were collected using a van Dorn sampler as described earlier. Immediately after collection, the samples were filtered through Whatman GF/C glass fibre filters (approx. 0.45 µm pore size). The filtered samples were preserved with 40 mg mercuric chloride and stored in the cold at approximately 4 ^{0}C in an insulated box during transportation to the laboratory. In the laboratory they were kept frozen for a maximum of 24 hours after collection prior to analysis.

A standard phosphate solution was made by dissolving 0.2197 g of potassium dihydrogen phosphate (KH_2PO_4) previously dried in an oven at 105 ^{0}C for 24 hours in distilled water and making the solution to 1 l. 1 ml of this solution contained 50 µg PO_4 - P. The standard solution was preserved with 1 ml of chloroform and stored in a dark bottle. Appropriate dilutions were made to give concentrations of 10, 20, 40, and 100 µg P l^{-1} .

To a 100 ml sample, 4 ml of molybdate reagent was added followed by 0.5 ml stannous chloride reagent with thorough mixing after each addition. Colour development took place after 10 - 12 minutes. Absorbance was measured at 690 nm wavelength on a Bausch & Lomb SP 88 spectrophotometer against a blank of distilled water and reagents. All samples, standards and reagents were held at ± 2 ^{0}C of room temperature because colour intensity and rate of development depend on temperature since 1 ^{0}C increase in temperature produces about 1% increase in colour (American Public Health Association, 1985). Following the measurements of absorbance of the standard solutions a standard curve was made by plotting concentration (µg PO_4 l^{-1}) against absorbance on a millimetre graph paper (Fig. 2). The concentrations were read off from the standard curve.

3.5.2 Nitrate-nitrogen (NO_3 - N)

The salicylate method was used for the determination of nitrate-nitrogen. Samples were obtained and filtered in the same way as for PO_4 - P analysis. The filtered samples were stored at about 4 ^{0}C in an insulated box containing ice blocks while being transported to the laboratory and later were kept in a refrigerator. Analysis was done within 24 hours after sample collection.

Standard nitrate solution was made by dissolving 0.7218 g of potassium nitrate (KNO_3) dried in an oven overnight at 105 ^0C in double distilled water and the solution made to 1 l and preserved with 2 ml chloroform. This solution contained 100 µg $NO_3 - N\ ml^{-1}$. Dilutions were made appropriately to obtain standard solutions containing 10, 20, 40 and 100 µg $NO_3 - N\ l^{-1}$. Replicates of both standards and samples were analyzed.

To 25 ml of the filtered water samples in a glass beaker was added 1 ml sodium salicylate solution and evaporated to dryness in the oven overnight. The residue was dissolved in 1 ml concentrated sulphuric acid before the beaker cooled and 50 ml double distilled water added, followed by 7 ml of NaOH - tartrate solution.

The solution was made to 100 ml in a volumetric flask, mixed thoroughly and the absorbance measured immediately at a wavelength of 420 nm using the Bausch & Lomb SF 88 spectrophotometer against a blank of double distilled water.
The standard series, the sample and the blanks were treated the same way. Absorbance measured for the standard solutions was plotted against concentration on a millimetre graph paper. A

Fig. 2. Standard curve for phosphate - phosphorus determination.

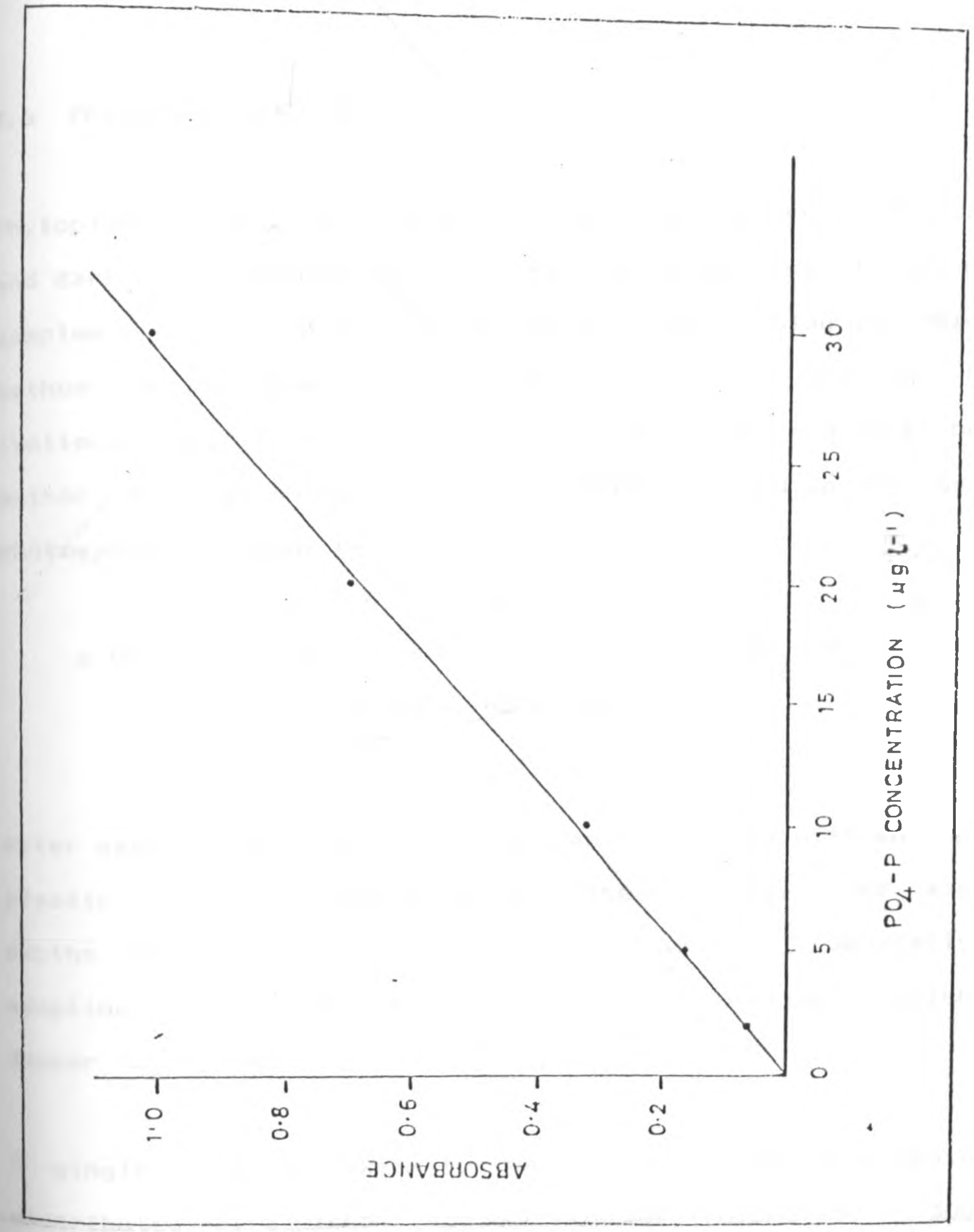


FIG. 2

straight line graph was obtained (Fig. 3) from which the NO_3 - N concentrations of samples were read off.

3.6 PRIMARY PRODUCTIVITY

Phytoplankton photosynthetic rates were determined by the light and dark bottle method following in situ incubation of lake water samples. Oxygen concentrations were measured using the Winkler method which has a high precision of ± 0.02 mg O_2 l^{-1} (Vollenweider, 1974; Talling, 1966). The light and dark bottle method measures rates of oxygen production based on the general photosynthetic redox reaction:

$$6\ CO_2 + 6\ H_2O \xrightarrow[\text{PIGMENT RECEPTOR}]{\text{LIGHT}} C_6H_{12}O_6 + 6\ O_2$$

Water samples were collected from various depths with an opaque, plastic van Dorn sampler as described before. The sampling depths were usuallly 0, 0.5, 1, 2 and 3 metres. Generally the sampling stations were shallow, except for station 3 which was deeper (Z_m = 7 m).

A single sample of lake water was collected from each depth and distributed by a siphon into BOD bottles (Volume 250 - 300 ml) made of glass, whose thickness was approximately 50 mm, with

Fig. 3. Standard curve for nitrate - nitrogen determination.

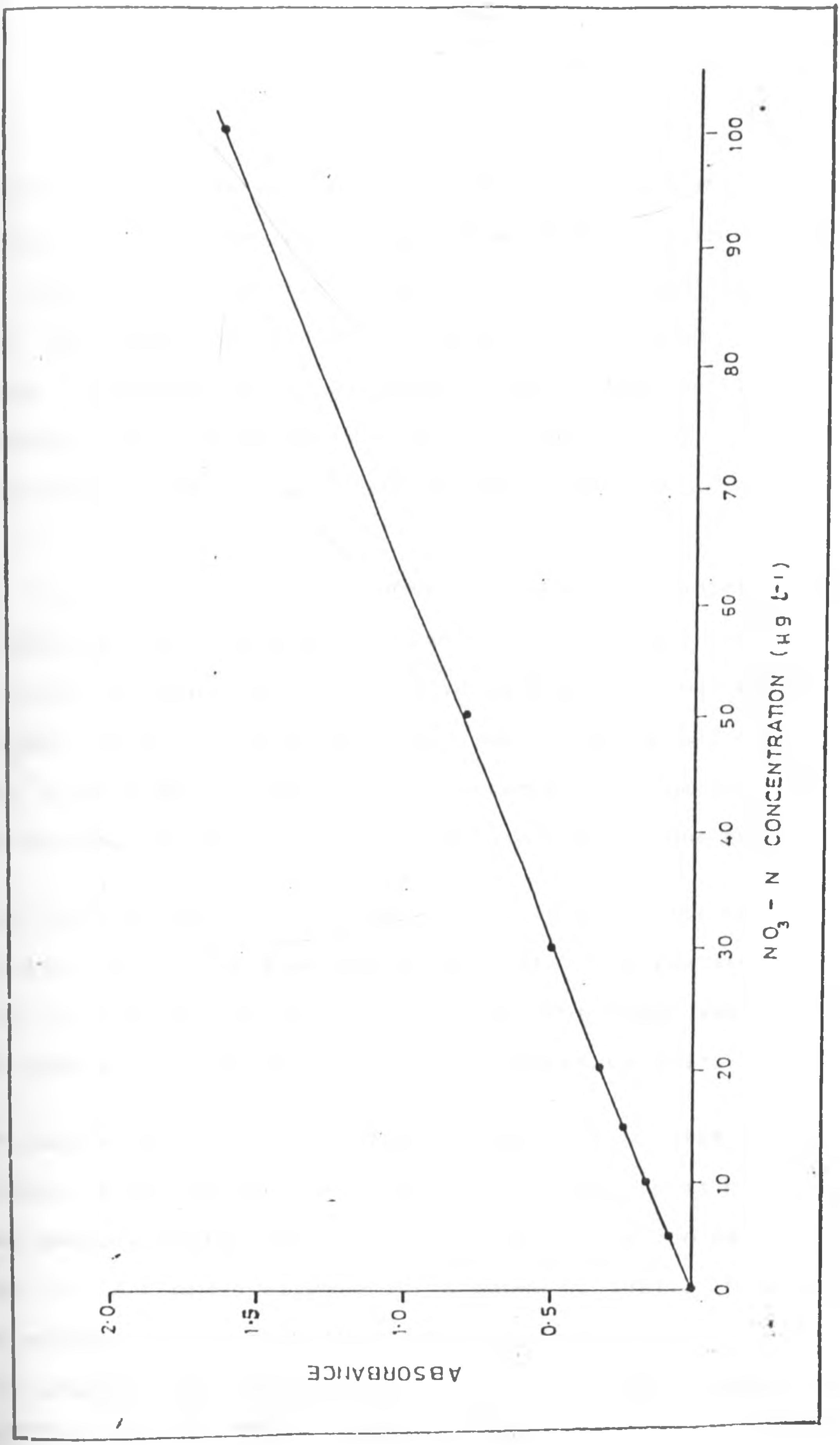

ABSORBANCE
2·0
1·5
1·0
0·5
0
10
20
30
40
50
60
70
80
90
100
NO_3 - N CONCENTRATION ($\mu g\ \ell^{-1}$)

FIG. 3

ground glass stoppers. One dark and two transparent bottles were filled and stoppered carefully. One of the transparent bottles was used to determine the initial oxygen concentration at the time for sampling. To its contents, 2 ml of $MnSO_4$ reagent was added, followed by 1 ml NaOH - NaI. The bottle was well stoppered and inverted several times to mix. It was left to stand pending further analysis of the oxygen concentration.

The light and the dark bottles were immediately suspended (incubated) at the depth of sampling. The dark bottles were darkened by wrapping them in several layers of black tape. The bottles were held in a vertical position by metal rods hanging from a rope whose upper end was attached to a wooden rod. The rod was then attached to two styrofoam floats, one on each end.

Thus the bottles were held vertically in the water column without sinking. To ensure that the experimental bottles did not change their horizontal position by drifting, the lower end of the rope was tied to a stone heavy enough to withstand drift.

The samples were incubated for periods ranging from 1 to 3 hours. Exposure times longer than this were avoided as it has been shown that photosynthetic rates decline with incubation periods longer than 4 - 6 hours (Vollenweider & Nauwerk, 1961). At the end of the exposure time, both the light and dark bottles were retrieved and treated as before to fix oxygen. All the operations were done in subdued light. When the flocculant in all the bottles had settled to the bottom third of the volume, 2 ml of concentrated H_2SO_4 was added to each carefully restoppering to avoid any air bubbles. The bottle was inverted several times to dissolve the flocculant. Two separate volumes of 100 ml from each bottle were titrated with standardized 0.0125 N sodium thiosulphate solution using starch indicator. The average volume of titrant in the two titrations was used in the final calculations of the oxygen concentrations. From the oxygen concentrations measured the following calculations of photosynthesis were made:

$$\text{Resp} = I - D$$
$$NP = L - I$$
$$GP = L - D$$

where Resp = respiratory activity
NP = net photosynthetic activity
GP = gross photosynthetic activity
I = initial oxygen concentration
L = oxygen concentration in the light bottle
D = oxygen concentration in the dark bottle

N.B. Only the gross productivity data were used in the discussions contained in this work, since gross productivity is the sum of net productivity and respiration and thus represents "total productivity".

3.6.1 Test of the method accuracy

The Winkler method of oxygen determination was tested against other methods and the result compared to judge its accuracy. After sampling, the oxygen concentration of the sample was often measured by dipping the probe of a pHox oxygen meter into the sample. The reading obtained was then compared with the result after titration following the Winkler method. The difference in the values obtained was found to be no more than ± 0.05 mg O_2 l^{-1} .

3.6.2 Daily photosynthetic rates

Estimation of daily photosynthetic rates based on short experiments that last only 1-3 hours is a rather difficult excercise. A number of methods have been suggested by various authors (e.g. Vollenweider, 1974; Platt. 1971 and Harmer et al. 1973). In this study the method of Talling (1965) was used. Here an empirically derived factor of 0.9 is multiplied by the number of hours of sunlight on the day of experiment and the hourly rate of photsynthesis.

It is thus assumed that photosynthetic rates remain uniform throughout the day, although they are bound to vary with varying light intensity and temperature which occur each day.

Calculation of hourly areal rates of photosynthesis was done by planimetric intergration of the area under the curve of volumetric rates.

3.6.3 Expression of values

The plus or minus (±) sign used in this work to express values invariably refers to standard deviations.

CHAPTER 4

RESULTS

4.1 PHYSICO-CHEMICAL FACTORS

4.1.1. TEMPERATURE

4.1.1.1 Seasonal Variation

The seasonal variation of surface water temperature within the Winam Gulf is shown in Fig. 4. Water temperature within the Gulf is more or less similar from one sampling station to another with very minor variations. Lower water temperature, however, is found in such locations as station 5 (Nyakach Bay) which is influenced by colder inflowing river water from the Nyando and Sondu Rivers. The range of surface water temperature measured in the Winam Gulf during the study period was 25.7 ± 0.4 ^{0}C to 27.6 ± 1.0 ^{0}C, which represents a range of 2.9 or 6.8% variation.

In February, 1986 the temperature was 26.3 ± 0.4 ^{0}C and rose to 26.8 ± 0.7 ^{0}C in May. There were minor fluctuations until August before rising to the maximum of 27.6 ± 1.0 ^{0}C in December.

Fig. 4. Seasonal variation in surface water temperature in the Winam Gulf as mean values for stations 1-5. Vertical bars represent standard deviation. The dashed line indicates a period during which no data were collected.

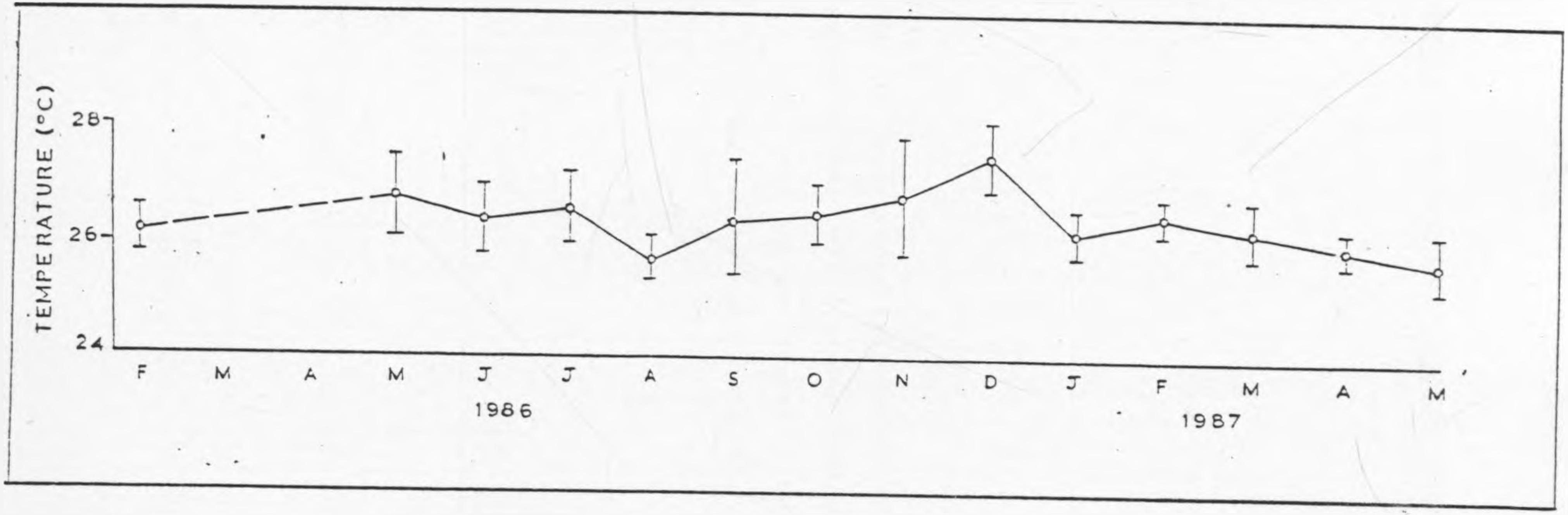


FIG. 4

Fig. 5. Solar radiation (A), evaporation (B) and rainfall (C) in the Gulf region during the period of study. Data provided by Meteorological Department, Kisumu. Dashed lines indicate a period during which no data were collected.

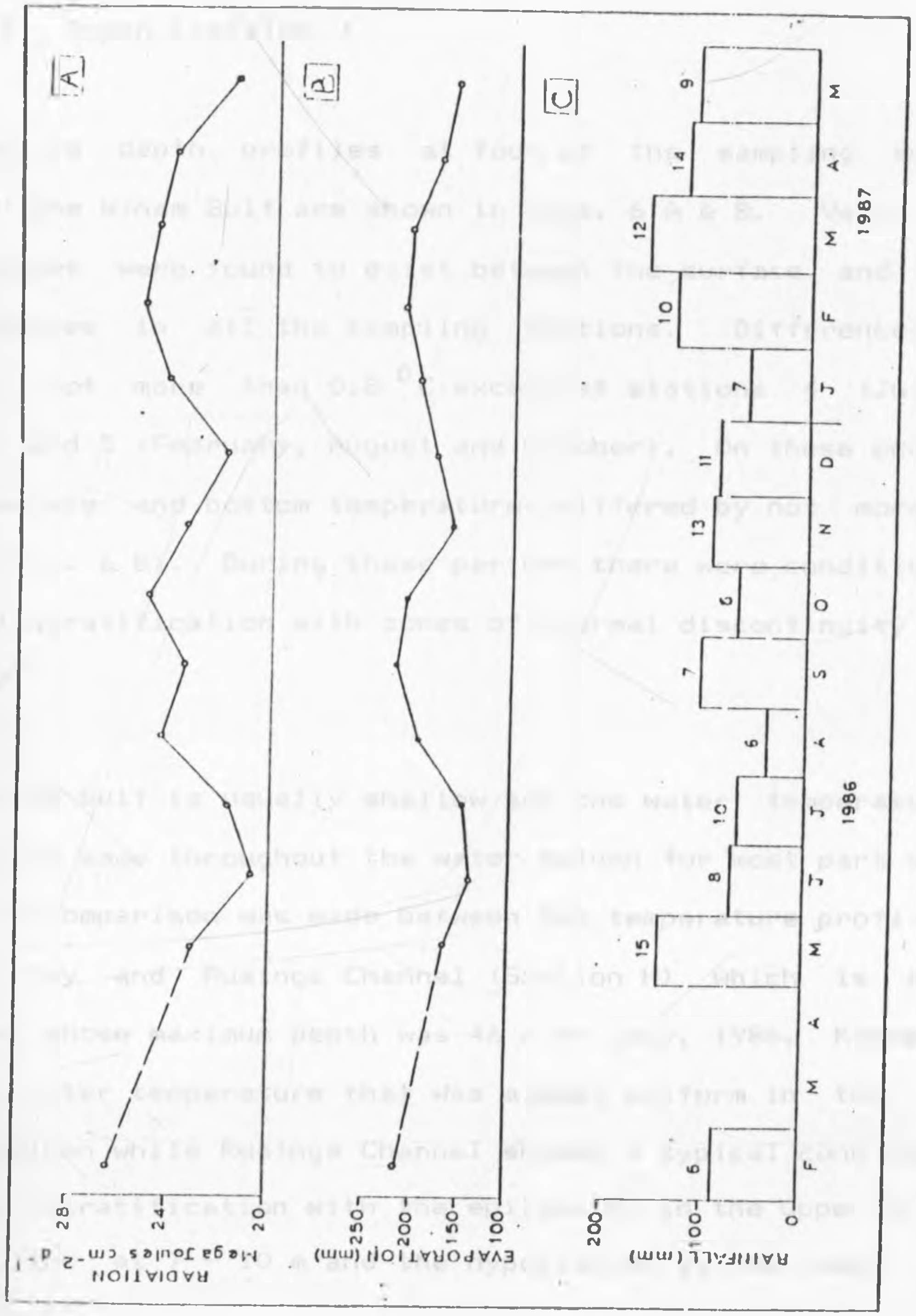


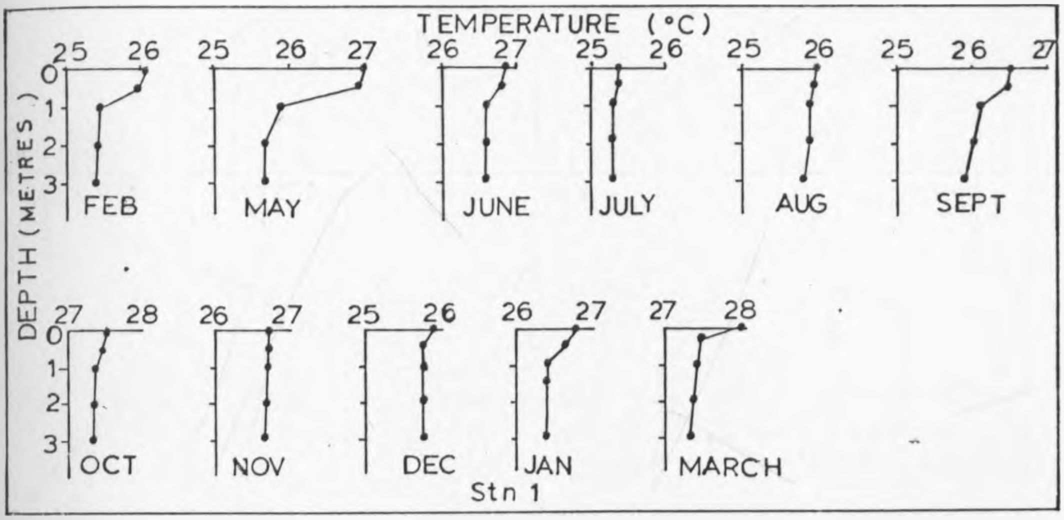
FIG. 5

4.1.1.2 Depth Profiles

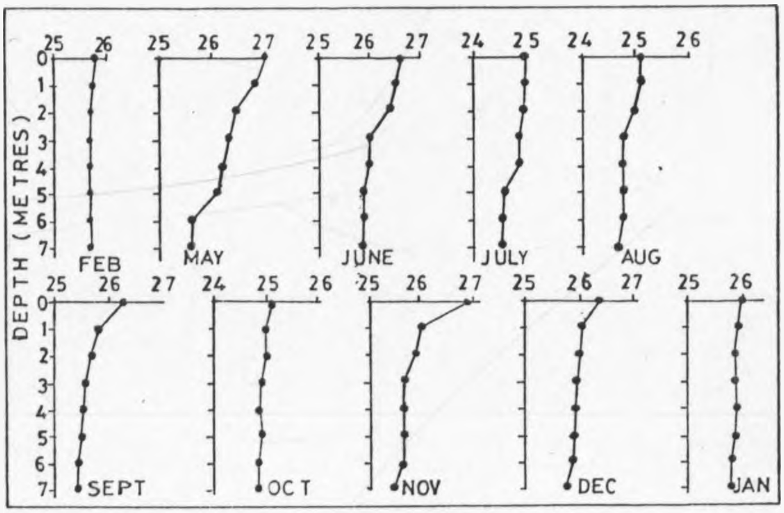
Temperature depth profiles at four of the sampling stations within the Winam Gulf are shown in Figs. 6 A & B. Very slight differences were found to exist between the surface and bottom temperatures in all the sampling stations. Differences were usually not more than 0.8 ^{0}C except at stations 4 (July and August) and 5 (February, August and October). On these occasions the surface and bottom temperatures differed by not more than 2 ^{0}C (Fig. 6 B). During these periods there were conditions of thermal stratification with zones of thermal discontinuity below 0.5 m.

The Winam Gulf is usually shallow and the water temperature is nearly the same throughout the water column for most part of the year. A comparison was made between the temperature profiles of Kisumu Bay and Rusinga Channel (Station H) which is a deep station whose maximum depth was 46 m in July, 1986. Kisumu Bay showed water temperature that was almost uniform in the entire water column while Rusinga Channel showed a typical condition of thermal stratification with the epilimnion in the upper 6 m, a thermocline at 7 - 10 m and the hypolimnion in the lower column (Fig. 7).

Fig. 6 A. Temperature profiles at station 1 (Kisumu Bay)
station 3 (Ndere Island).



Stn 1



Stn 3

FIG. 6 A

Fig. 6 B. Temperature profiles at station 4 (off Dunga) and station 5 (Nyakach Bay).

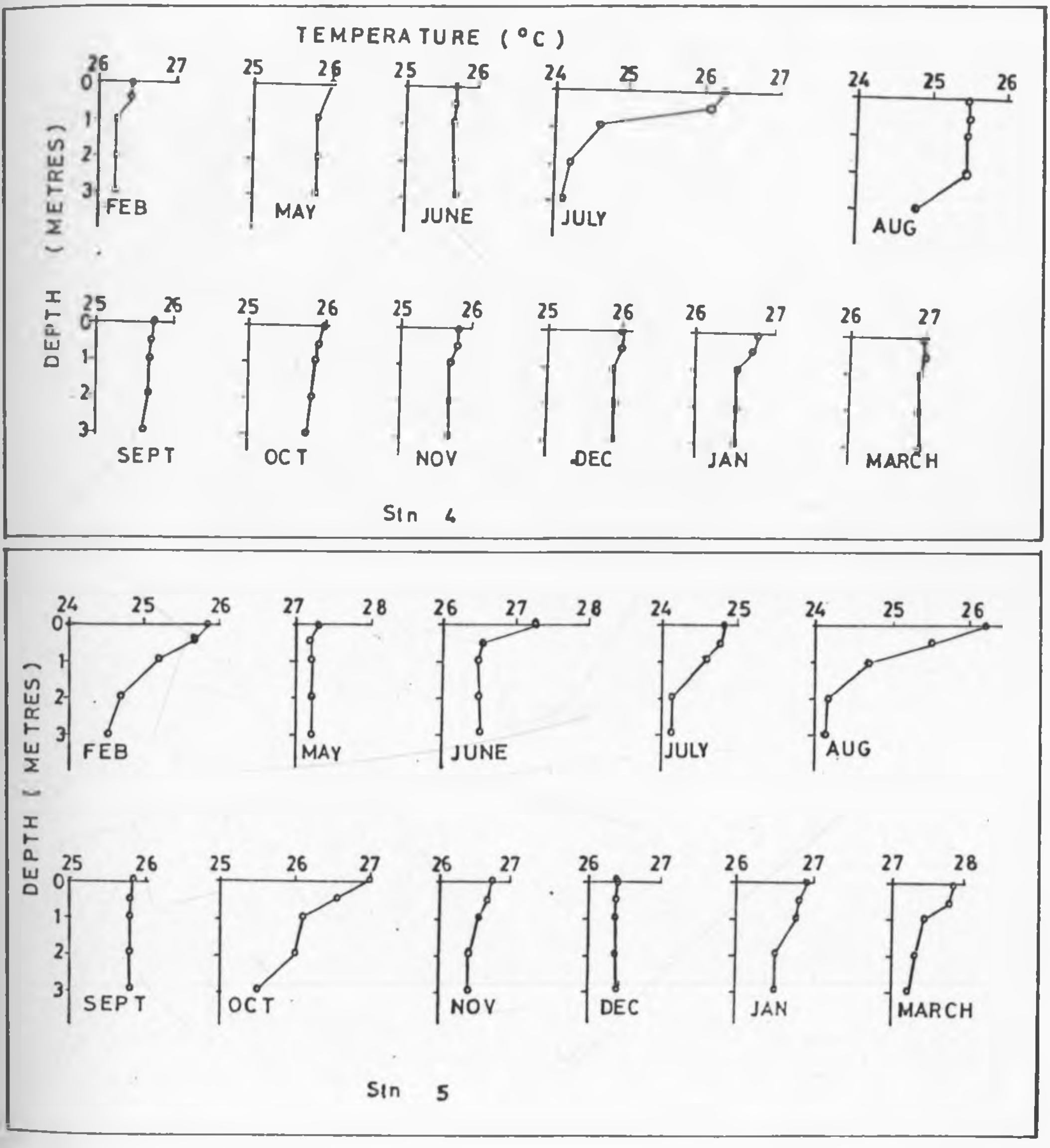

TEMPERATURE (°C)
DEPTH (METRES)
FEB
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC
JAN
MARCH
Stn 4
DEPTH (METRES)
FEB
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC
JAN
MARCH
Stn 5

FIG. 6 B

Fig. 7. Temperature profiles at station H (Rusinga Channel) showing stratification and at station 1 (Kisumu Bay) showing near -isothermal condition.

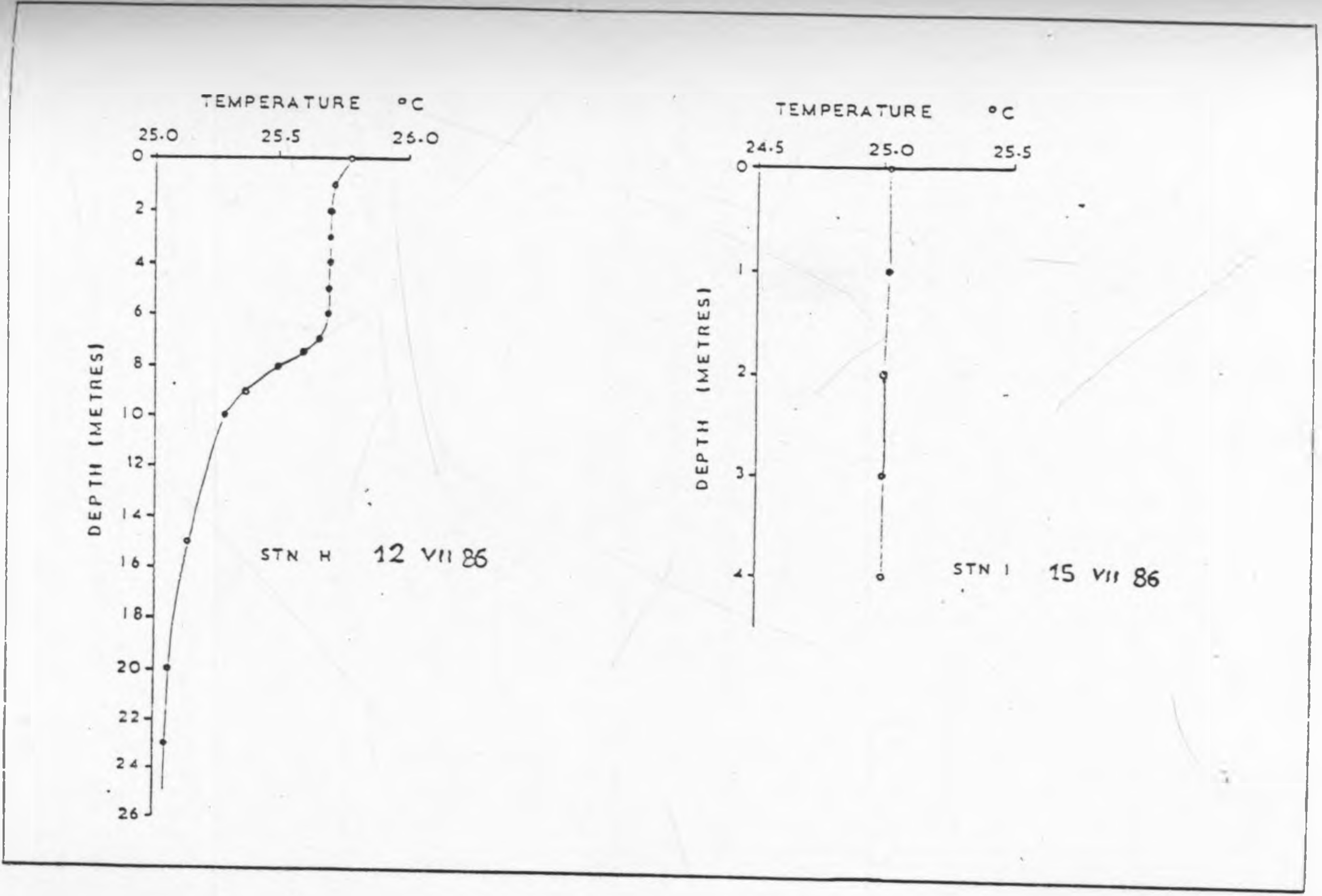

TEMPERATURE °C
25.0
25.5
26.0
DEPTH (METRES)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
STN H 12 VII 86
TEMPERATURE °C
24.5
25.0
25.5
DEPTH (METRES)
0
1
2
3
4
STN I 15 VII 86

FIG . 7

Fig. 8. Diurnal changes in turbidity (A), alkalinity (B), pH (C), water and air temperatures (D) and dissolved oxygen (E) at Nyakach Bay on 29 to 30 December 1986.

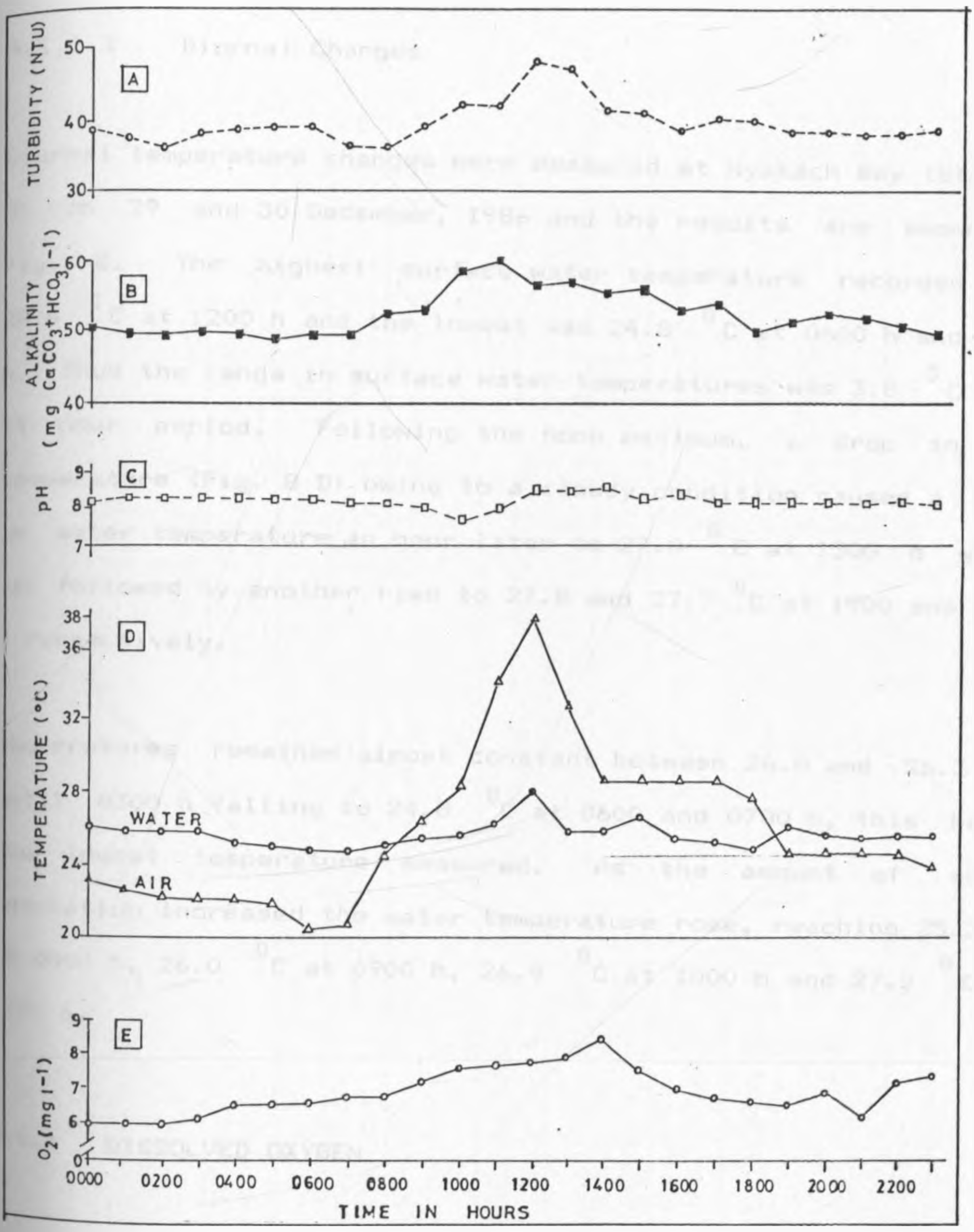

TURBIDITY (NTU)
50
40
30
A
ALKALINITY (mg CaCO$_3$+HCO$_3$ l-1)
60
50
40
B
pH
9
8
7
C
TEMPERATURE (°C)
38
36
32
28
24
20
D
WATER
AIR
O$_2$(mg l-1)
9
8
7
6
0
E
0000
0200
0400
0600
0800
1000
1200
1400
1600
1800
2000
2200
TIME IN HOURS

FIG. 8

4.1.1.3 Diurnal Changes

Diurnal temperature changes were measured at Nyakach Bay (Station 5) on 29 and 30 December, 1986 and the results are shown in Fig. 8. The highest surface water temperature recorded was 28.6 ^{0}C at 1200 h and the lowest was 24.8 ^{0}C at 0600 h and 0700 h. Thus the range in surface water temperatures was 3.8 ^{0}C in a 24 hour period. Following the noon maximum, a drop in air temperature (Fig. 8 D) owing to a cloudy condition caused a drop in water temperature an hour later to 27.0 ^{0}C at 1300 h which was followed by another rise to 27.8 and 27.7 ^{0}C at 1900 and 2000 h respectively.

Temperatures remained almost constant between 26.0 and 26.3 ^{0}C until 0300 h falling to 24.8 ^{0}C at 0600 and 0700 h, this being the lowest temperature measured. As the amount of solar insolation increased the water temperature rose, reaching 25.2 ^{0}C at 0800 h, 26.0 ^{0}C at 0900 h, 26.9 ^{0}C at 1000 h and 27.2 ^{0}C at 1100 h.

4.1.2 DISSOLVED OXYGEN

4.1.2.1 Seasonal Changes in Surface Oxygen

Table 2 shows the monthly concentrations of dissolved oxygen measured at three of the sampling stations in the Winam Gulf

Table 2. Seasonal changes in dissolved oxygen, pH, conductivity and alkalinity at stations 1,3 and 5 in the Winam Gulf.

		1986											1987					
		F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	$\bar{x}$	SD
STN 1	DISSOLVED OXYGEN (mg l^{-1})	8.0	-	-	8.9	8.6	8.4	7.4	7.3	8.2	8.0	8.0	8.1	8.5	8.6	8.2	7.2	8.1	0.45
	pH	8.0	-	-	9.0	8.7	8.5	8.4	8.2	8.3	8.1	8.7	8.6	8.9	8.9	8.0	8.1	8.4	0.38
	CONDUCTIVITY ($\mu S\ cm^{-1}$)	138	-	-	135	141	145	148	130	132	125	137	120	140	-	130	135	135	7.78
	ALKALINITY (mg $Co\ CO_3 + HCO_3\ l^{-1}$	73	-	-	68	70	75	77	71	72	62	70	63	58	64	62	60	67.5	5.95
STN 3	DISOLVED OXYGEN (mg l^{-1})	7.7	-	-	8.3	9.4	8.2	8.4	7.7	7.4	8.0	7.4	7.6	8.2	8.7	8.2	8.0	8.0	0.53
	pH	8.2	-	-	7.8	8.4	7.5	8.0	8.2	8.9	7.5	9.0	8.8	8.6	8.2	7.9	8.7	8.2	0.61
	CONDUCTIVITY ($\mu S\ cm^{-1}$)	135	-	-	140	135	135	145	132	138	135	139	140	130	132	110	118	131.9	11.31
	ALKALINITY (mg $Co\ CO_3 + HCO_3\ l^{-1}$	50	-	-	50	55	56	57	60	62	70	72	57	59	52	54	53	57.9	6.63
STN 5	DISOLVED OXYGEN (mg l^{-1})	9.0	-	-	9.2	8.9	11.1	8.8	7.9	8.5	7.1	6.8	8.6	8.8	8.7	8.3	7.8	8.5	1.03
	pH	7.8	-	-	7.6	8.0	7.8	7.6	8.2	8.0	8.0	8.8	8.0	7.6	8.1	8.0	8.1	8.0	0.29
	CONDUCTIVITY ($\mu S\ cm^{-1}$)	130			125	139	142	148	135	132	131	146	137	128	-	123	134	134.6	7.64
	ALKALINITY (mg $CoCO_3 + HCO_3\ l^{-1}$	73			70	74	75	79	74	72	73	77	68	70	56	68	64	70.9	57.9

namely, Kisumu Bay, (Station 1), Ndere Island (Station 3) and Nyakach Bay (Station 5). The highest concentration measured during the study period was 11.1 mg O_2 l^{-1} in July, 1986 at Nyakach Bay. The mean concentrations of surface oxygen varied little horizontally among the sampling stations. The highest mean concentration was recorded at Nyakach Bay (8.6 ± 1.0 mg O_2 l^{-1}). Following this was Kisumu Bay (8.1 ± 0.5 mg l^{-1}). The lowest mean oxygen concentration was at Ndere Island (8.0 ± 0.6 mg l^{-1}). The highest oxygen concentrations in the Gulf were recorded in the period May to July, 1986. Maximum oxygen concentration of 8.9 mg l^{-1} at Kisumu Bay was recorded in May while the maximum of 9.45 and 11.1 mg O_2 l^{-1} were recorded at Ndere Island and Nyakach Bay, respectively, in July.

4.1.2.2 Vertical distribution

Dissolved oxygen profiles are shown in Fig. 9. Concentrations were normally higher near the surface than in the lower water layers in all cases. Concentrations in the upper 0.5 m layer were usually uniform. However, measurements made on 5 February, 1986 at Kisumu Bay showed that dissolved oxygen concentration was lower at 0.5 m than at the surface and at 1 m.

Levels of dissolved oxygen show that in the Winam Gulf, the water column is fairly homogeneous with very narrow differences between the surface and the bottom values. The biggest difference of 2.8

Fig. 9. Dissolved oxygen profiles at the routine sampling stations on various dates and as compared with station H (Rusinga Channel)

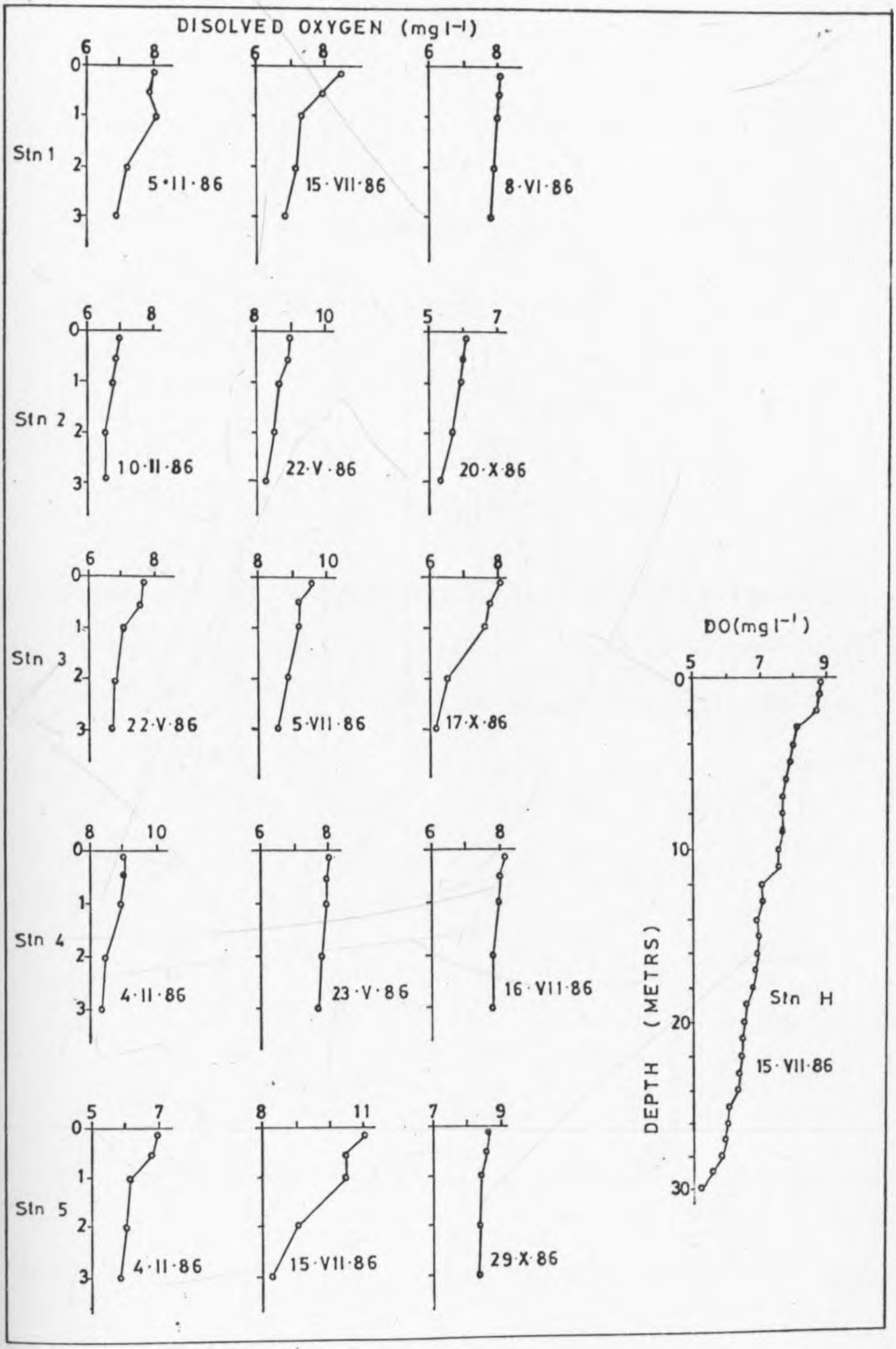

DISOLVED OXYGEN (mg l^{-1})
Stn 1
5·II·86
15·VII·86
8·VI·86
Stn 2
10·II·86
22·V·86
20·X·86
Stn 3
22·V·86
5·VII·86
17·X·86
Stn 4
4·II·86
23·V·86
16·VII·86
Stn 5
4·II·86
15·VII·86
29·X·86
DO(mg l^{-1})
DEPTH (METRS)
Stn H
15·VII·86
0
1
2
3
5
6
7
8
9
10
11
20
30

FIG. 9

Fig. 10. Concentration of dissolved oxygen in the water column at 0900 h (o——o). 1200 h (o-----o) and 1500 h (●——●) on 12.8.86 at Kisumu Bay.

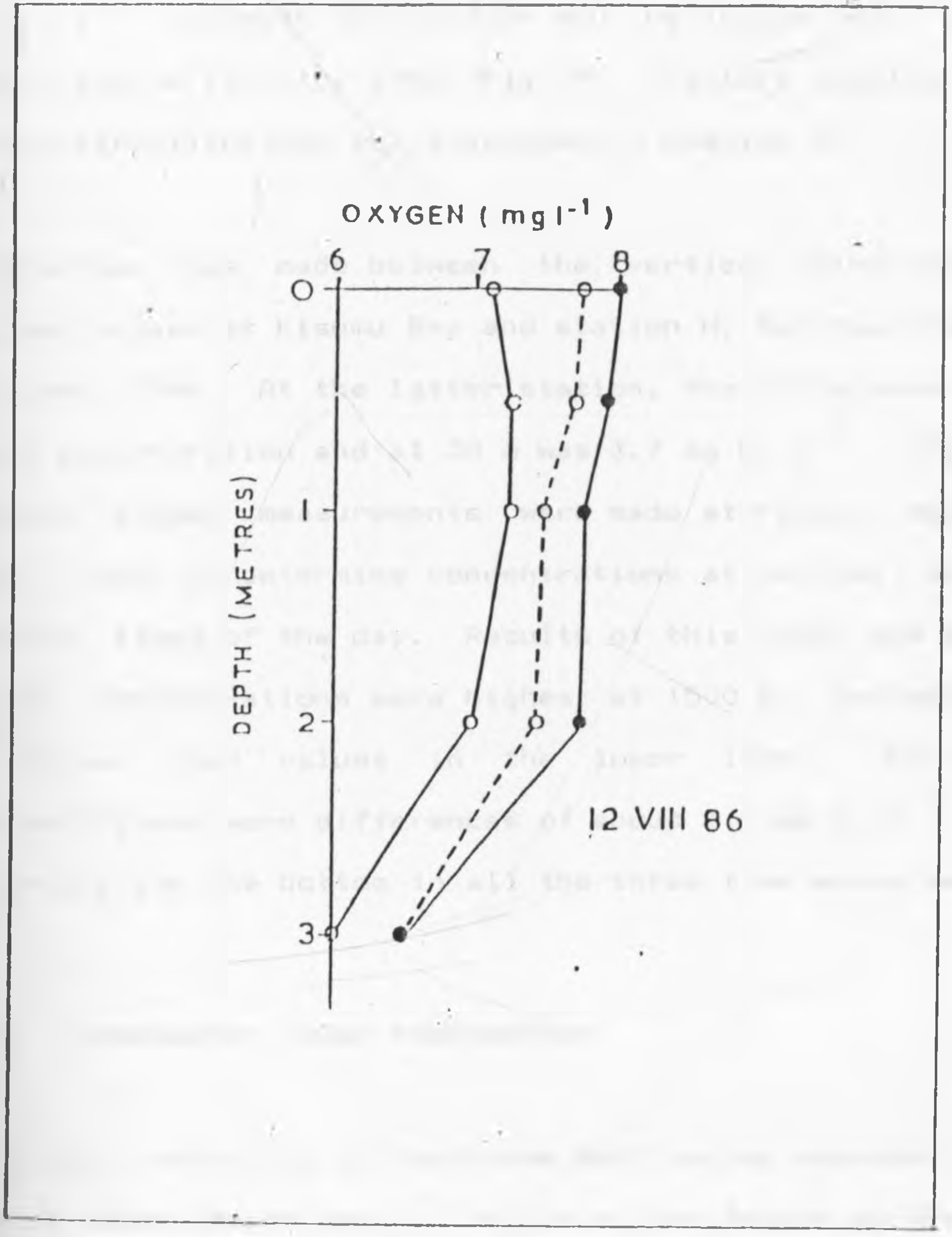


FIG. 10

mg O_2 l^{-1} between the surface and the bottom was found at Nyakach Bay on 15 July, 1986 (Fig. 9). Factors leading to this apparent stratification are discussed in Chapter 5.

A comparison was made between the vertical distribution of dissolved oxygen at Kisumu Bay and station H, Rusinga Channel, on 15 August, 1986. At the latter station, the difference between surface concentration and at 30 m was 3.7 mg O_2 l^{-1} (Fig. 9). Dissolved oxygen measurements were made at Kisumu Bay on 12 August, 1986 to determine concentrations at various depths at different times of the day. Results of this study are shown in Fig. 10. Concentrations were highest at 1500 h. Surface values were higher than values in the lower layer. During this experiment there were differences of about 1.0 mg O_2 l^{-1} between the surface and the bottom in all the three time measurements.

4.1.3. UNDERWATER LIGHT PENETRATION

Secchi disc visibility in the Winam Gulf varies seasonally. The range of Secchi depth was 0.2 to 1.4 m, the former at Nyakach Bay (Station 5) and the latter at Ndere Island (Station 3). The seasonal variation in Secchi disc visibility in relation to chlorophyll a at Kisumu Bay is illustrated in Fig. 11. Here, the least transparency was recorded in June, 1986 when the Secchi depth was 0.3 m. During this time, a maximum chlorophyll a concentration of 44 µg l^{-1} was measured. The highest Secchi

Fig. 11. Seasonal variation in Secchi disc visibility and chlorophyll a at Kisumu Bay.

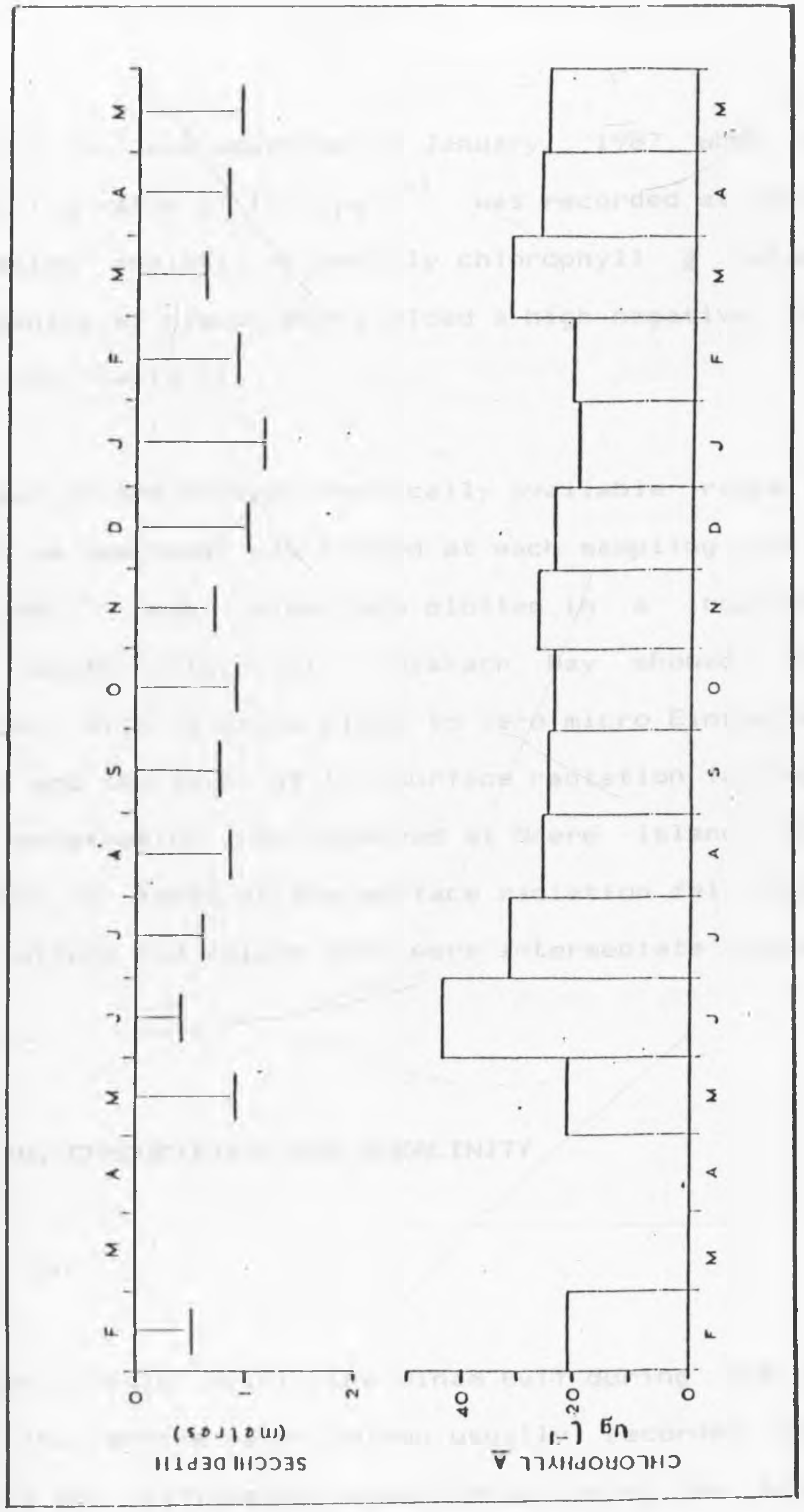


FIG. 11

depth (1.2 m) was measured in January, 1987 when the least chlorophyll a value of 19.6 µg l^{-1} was recorded at this station. A regression analysis of monthly chlorophyll a values versus Secchi depths at Kisumu Bay yielded a high negative correlation ($r = -0.695$, Table 3).

Penetration of the photosynthetically available radiation (PAR, 400 - 700 nm spectrum) was traced at each sampling station during August 1986. Mean values are plotted in a logarithmic form against depth (Fig. 12). Nyakach Bay showed the least penetration with a value close to zero micro Einsteins m^{-2} S^{-1} at 1.5 m and the level of 1 % surface radiation falling at 1 m. Maximum penetration was observed at Ndere Island (station 3) where the 1% level of the surface radiation fell below 4 m. Other stations had values that were intermediate between these two.

4.1.4 pH, CONDUCTIVITY AND ALKALINITY

4.1.4.1 pH

pH varied little within the Winam Gulf during the period of study. The entire water column usually recorded near-uniform values of pH. Differences encountered during the study period did not exceed 0.5 units between the surface and the bottom water. pH was generally lower in enclosed bays (e.g Nyakach Bay)

Table 3. Correlation coeffecients (r) obtained from regression analyses between various parameters related to primary productivity.

Parameters	r
Productivity vs chlorophyll a	0.873 *
Productivity vs phosphate	0.913 *
Productivity vs nitrate	0.323
Chlorophyll a vs phosphate	0.915 *
Chlorophyll a vs nitrate	0.569 *
Chlorophyll a vs Secchi	-0.695 *
Phosphate vs nitrate	0.463

* Significant at 0.05 level of significance

than in the more open stations such as Ndere Island. Seasonal changes in pH in the Winam Gulf are shown in Fig. 13. There was very little fluctuation during the period of study. The range was 7.5 - 9.0 (see also Table 2).

4.1.4.2 Conductivity

The electrical conductance in the Winam Gulf water varies with the seasons being generally higher during the dry season. It shows very little vertical variation.

Conductivity rose in July to August, 1986 and in December, 1986 (Fig. 13) both of which were relatively drier periods (Fig. 5). Maximum conductivity (148 uS cm^{-1}) was recorded at Ndere Island in May, 1987.

4.1.4.3 Alkalinity

Like pH and conductivity, alkalinity showed little vertical variation. Differences between surface and bottom values were found not to exceed 10 mg $CaCO_3$ + HCO_3 l^{-1} during the present investigations. The lowest alkalinity encountered was 52 mg $CaCO_3$ + HCO_3 l^{-1} at Ndere Island (station 3) in February and May, 1986. The highest was 77 mg $CaCO_3$ + HCO_3 l^{-1} at Nyakach

Fig. 12. Attenuation of the photosynthetically active radiation (PAR) at various sampling stations in the Winam Gulf.

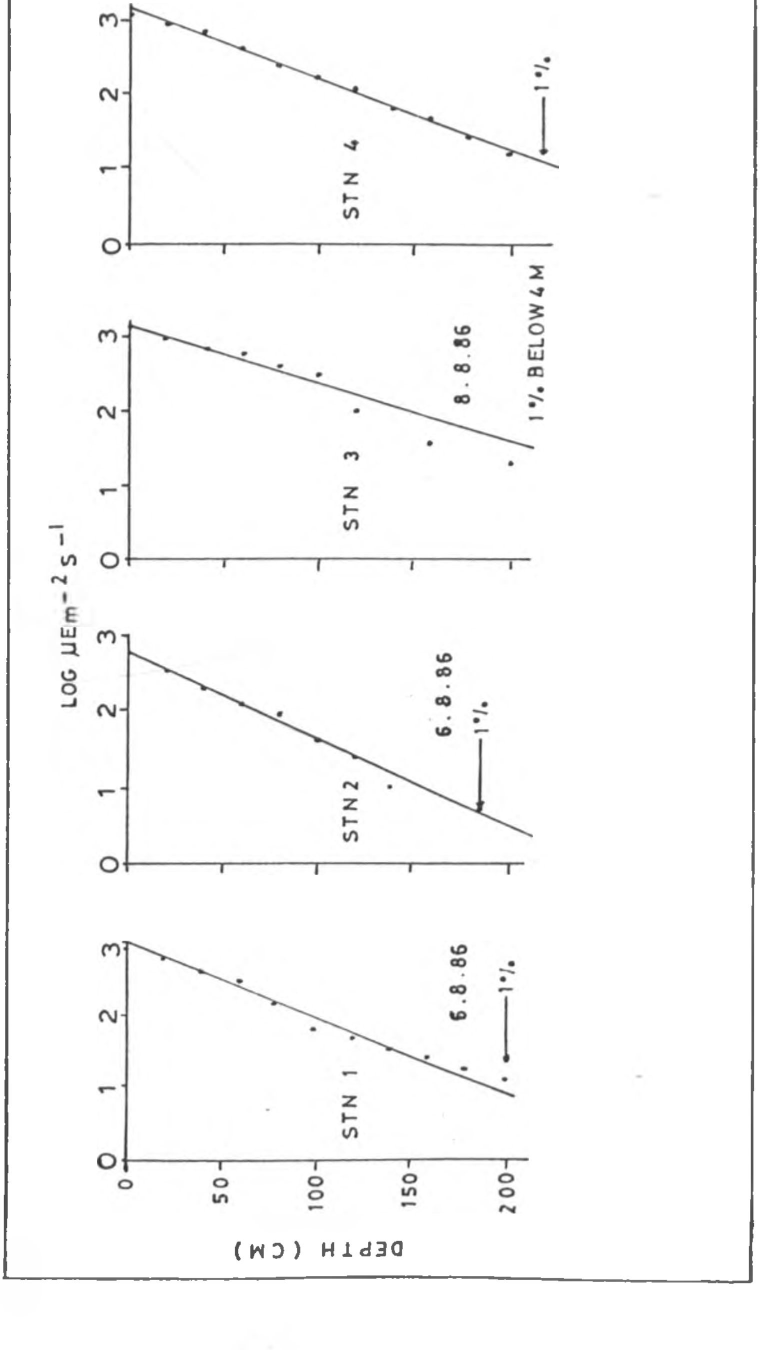

DEPTH (CM)
0
50
100
150
200
LOG µEm^{-2} s^{-1}
0
1
2
3
STN 1
6.8.86
1%
STN 2
6.8.86
1%
STN 3
8.8.86
1% BELOW 4M
STN 4
1%
STN 5
8.8.86
1%

FIG. 12

Fig. 13. Seasonal variation in conductivity (●——●), alkalinity (□——□) and pH (○——○) at stations 1, 3, and 5.

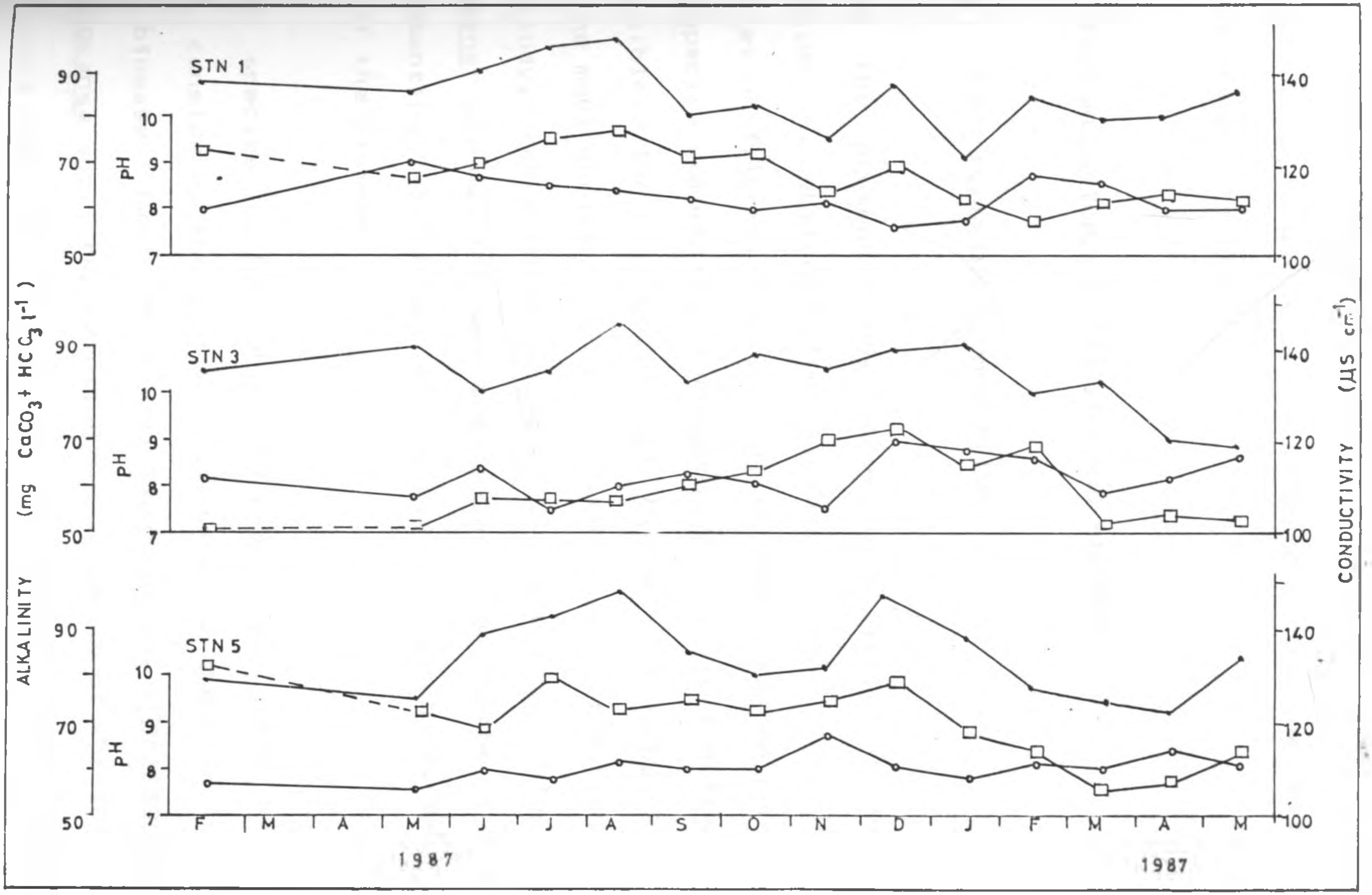

STN 1
STN 3
STN 5
ALKALINITY (mg CaCO$_3$ + HCC$_3$ l^{-1})
90
70
50
pH
10
9
8
7
CONDUCTIVITY (µS cm^{-1})
140
120
100
F
M
A
M
J
J
A
S
O
N
D
J
F
M
A
M
1987
1987

FIG. 13

Bay (Station 5) in December of the same year. The minimum and maximum values were thus encountered during the wet and dry seasons, respectively.

4.2 PHYTOPLANKTON COMPOSITION AND BIOMASS

4.2.1 PHYTOPLANKTON COMPOSITION

During the present study, there was little or no vertical variation in phytoplankton biomass. Counts of algal cells, colonies or filaments showed that the water column contained the same species composition throughout and vertical differences were negligible. The blue-green alga, Microcystis aeruginosa Kutzing. was the most dominant species in the Winam Gulf during the period of study, representing about 67 % of the total algal biomass. Anabaena sp. was the next most abundant among the Cyanophyceae, representing 5 % followed by Lyngbya sp., which represented about 4 % of the biomass.

Other species of Cyanophyceae encountered in the algal counts were considered insignificant in terms of their contribution to the biomass. Among these were Chroococcus, Merismopaedia and Aphanocapsa spp., representing less than 2% of the total biomass. The most important Chlorophytes included Oocystis, Staurastrum, and Pediastrum spp. Others included Scenedesmus, Cosmarium and Staurastrum, spp. but only the more common ones were considered.

Nitzschia sp. was the most abundant diatom species in the Gulf and was followed by Melosira sp. Others that were encountered in the course of investigations included Synedra, Diatoma and Surirella spp. A list of the major phytoplankton species found in the Winam Gulf appears in Appendix 10.

4.2.2 PHYTOPLANKTON BIOMASS

Table 4 shows the variation of the biomass of the most dominant algal species in the Winam Gulf. The bulk of the biomass was contributed by the Cyanophyte species, Microcystis aeruginosa Kutzing. in all the sampling stations. The seasonal distribution of M. aeruginosa and Anabaena sp., the two most important blue-green algae in the Gulf is shown in Fig. 14. Both these species contributed the highest biomass in the lake. At Nyakach Bay (Station 5) Anabaena sp. showed a peak with a biomass of 16.2 mg m^{-3} and a peak with 15.3 mg m^{-3} at Kisumu Bay (Station 1) in May, 1986.

Microcystis aeruginosa Kutzing. contributed the highest biomass at all the sampling stations. A biomass of 150 mg m^{-3} was recorded at Nyakach Bay in June, this being the highest encountered during the study.

Both M. aeruginosa and Anabaena sp. followed a pattern of distribution that was basically the same. Their biomass

Table 4. Seasonal changes in the biomass of some main algal spcies in the Winam Gulf. The data represent mean values for stations 1 - 5 .

	MAY	JUNE	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR
		1986								1987		
Anabaena sp.	8.9	8.6	7.3	6.8	6	6.2	0	0	12.9	8	8.8	7.4
Microcystis aeruginosa Kutzing.	128	108	120	93	89	96	62	74	6.8	74	96	100
Lyngbya sp.	11.4	1.5	1.1	2.8	3.4	5.1	6.2	5.4	7.12	2.28	5.7	10.2
Nitzschia sp.	6.7	4.8	5	7.7	6.7	3.8	4.3	7.6	7.9	9	6.9	5.6
Synedra sp.	7.5	2	2.5	4.5	5.2	3.7	4.7	5	4.2	7.5	9.2	8.2
Melosira sp.	0.9	0.7	1.9	2.3	2.2	1	1.3	1	1.2	1.6	2.1	1.5
Oocystis sp.	10.3	9.3	6.4	4.3	6	4.3	4.8	7.6	23.2	24	20	12.5
Total	173.7	134.9	144.2	121.9	118.5	120.1	83.3	100.6	63.32	126.38	148.7	145.4
$\overline{X}$	24.8	19.3	20.6	17.4	16.9	17.2	13.9	16.8	9	18.1	21.2	20.8

Fig. 14. Seasonal variation in the biomass of two Cyanophyte species, _Anabaena sp_. and _Microcystis aeruginosa_ Kutzing. in the Winam Gulf.

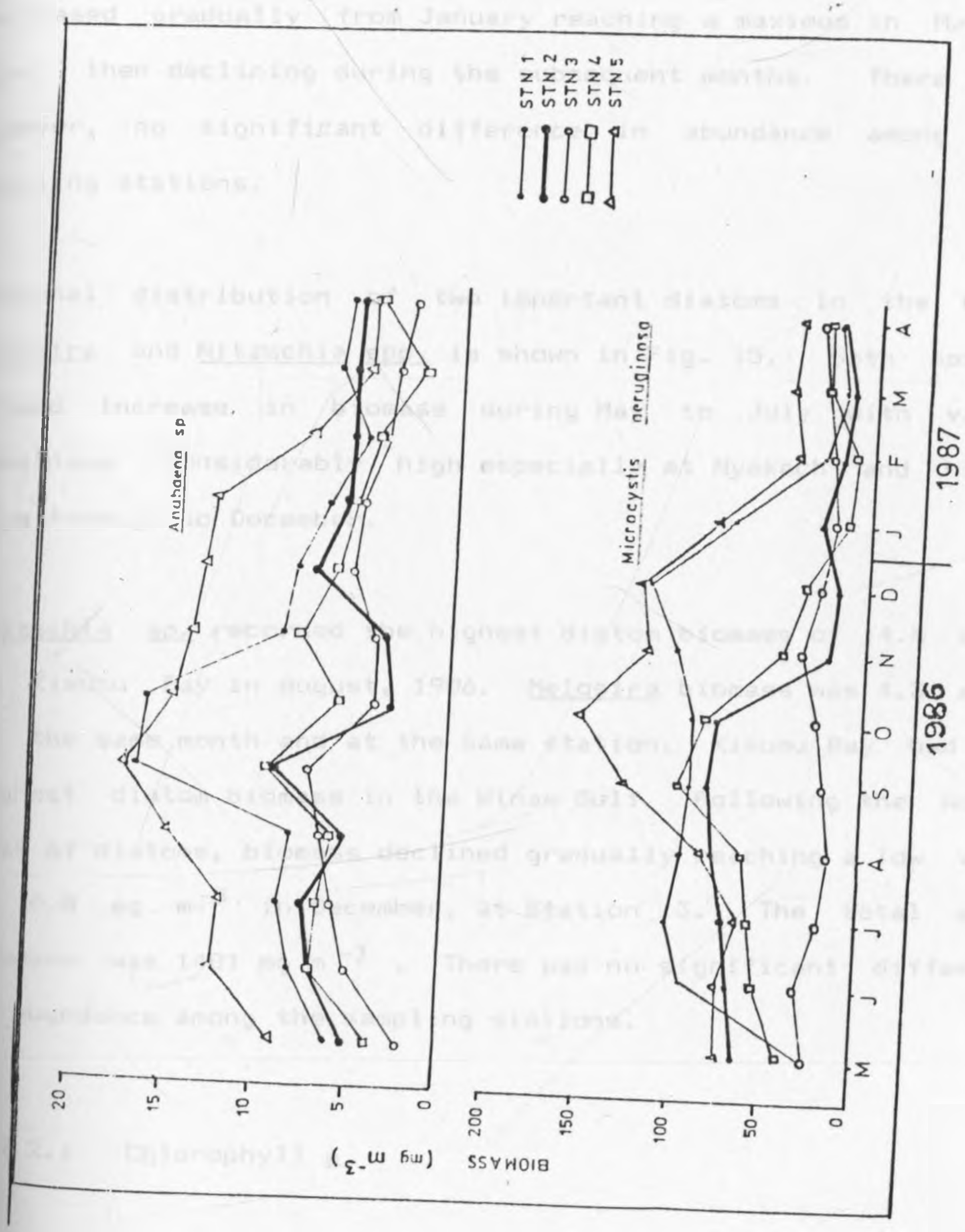


FIG. 14

increased gradually from January reaching a maximum in May to June, then declining during the subsequent months. There was, however, no significant difference in abundance among the sampling stations.

Seasonal distribution of two important diatoms in the Gulf, Melosira and Nitzschia spp. is shown in Fig. 15. Both species showed increase in biomass during May to July with values remaining considerably high especially at Nyakach and Kisumu Bays through to December.

Nitzschia sp. recorded the highest diatom biomass of 14.4 mg m^{-3} at Kisumu Bay in August, 1986. Melosira biomass was 4.3 mg m^{-3} at the same month and at the same station. Kisumu Bay had the highest diatom biomass in the Winam Gulf. Following the August peak of diatoms, biomass declined gradually reaching a low value of 0.8 mg m^{-3} in December, at Station 3. The total algal biomass was 1481 mg m^{-3} . There was no significant difference in abundance among the sampling stations.

4.2.2.1 Chlorophyll a

4.2.2.1.1 Seasonal Variation

The seasonal variation of chlorophyll a in the Winam Gulf at the 0.5 m depth is shown in Fig. 16. There were clearly two peaks of

Fig. 15. The seasonal variation in the biomass of two diatom species, Nitzschia and Melosira spp. in the Winam Gulf.

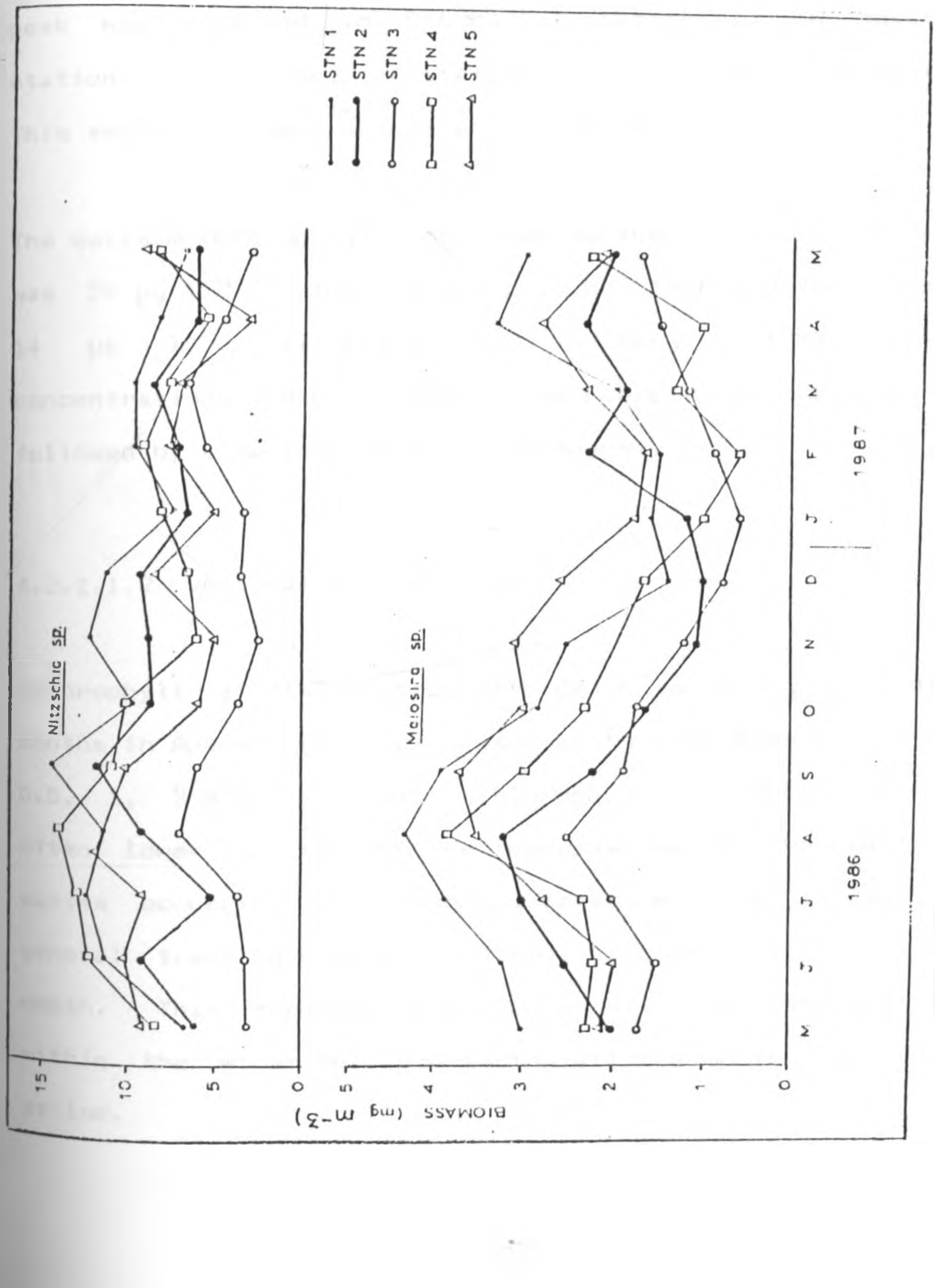

Nitzschia sp.
Melosira sp.
BIOMASS (mg m⁻³)
15
10
5
0
5
4
3
2
1
0
M J J A S O N D J F M A M
1986
1987
STN 1
STN 2
STN 3
STN 4
STN 5

FIG. 15

chlorophyll a concentration. There was the first higher maximum in June at all the sampling stations except Nyakach Bay (station 5) where this peak was observed in May. The second and minor peak was observed in October at station 2, in November at station 3, in December at station 4 and in January at station 5. This second peak was absent at station 1.

The maximum chlorophyll a measured during the entire study period was 50 μg l^{-1} at Nyakach Bay in May 1986 and the minimum was 14 μg l^{-1} at Kisumu Bay in April, 1987. Generally concentrations rose gradually from February to the June maximum followed by a decline in July and August.

4.2.2.1.2 Vertical Distribution

Chlorophyll a distribution with depth is shown for different months in Appendices 1-9. Measurements were made at the surface, 0.5, 1, 2 and 3 m depths. Chlorophyll a concentrations were often lower at the surface than just below the surface with maxima occurring at 0.5 m and sometimes at 1 m depths. The general trend was however, diminishing values with increasing depth. This trend was observed at all the sampling stations within the Winam Gulf and during all the months of the study period.

Fig. 16. Seasonal variation in chlorophyll a concentration at 0.5 m depth in the Winam Gulf, stations 1 to 5. Dashed lines indicate a period during which no data were collected.

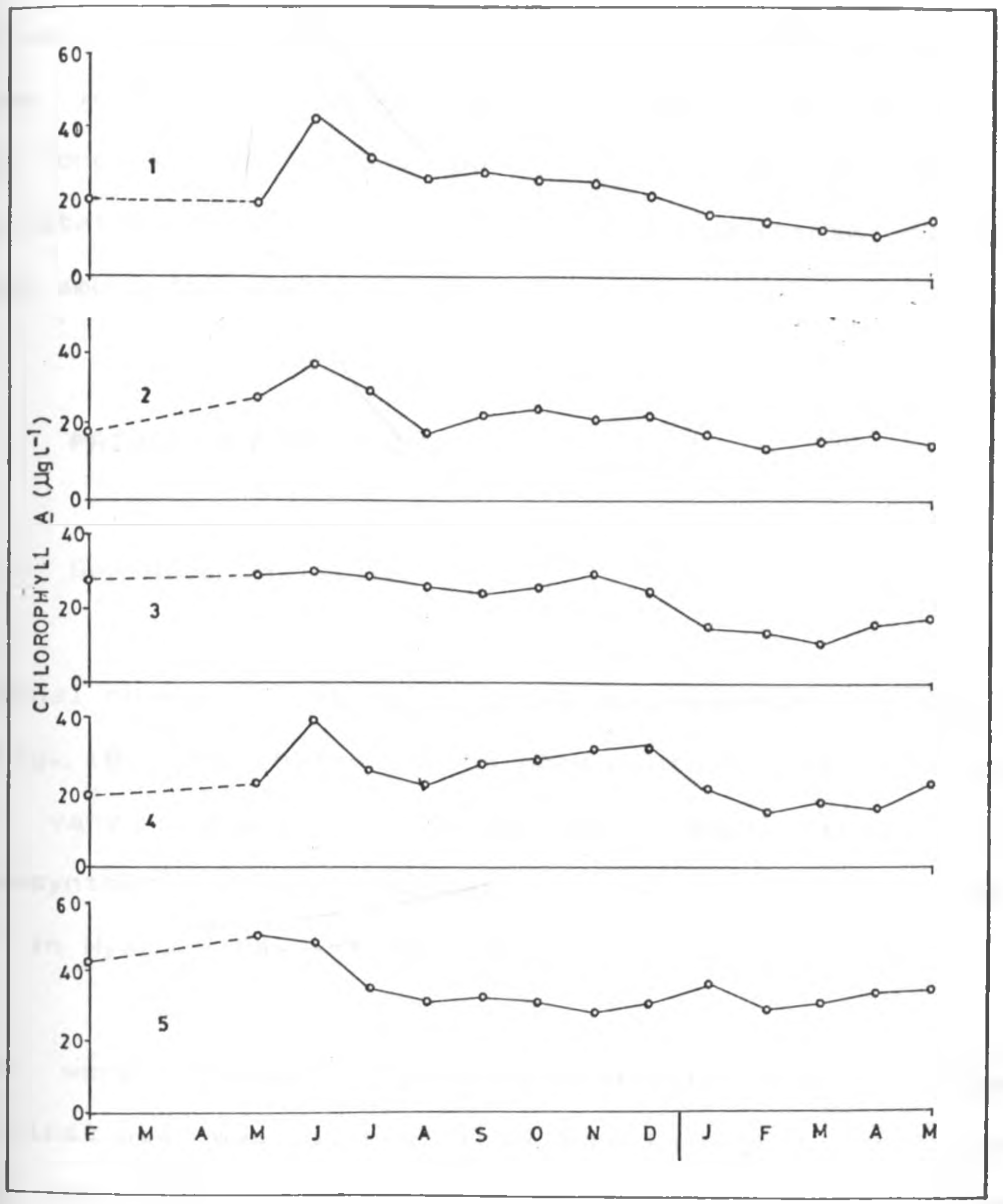


FIG. 16

The annual mean chlorophyll a at the 0.5 m depth was calculated for each of the sampling stations in the Gulf and the results are shown in Fig. 17. Nyakach Bay (Station 5), showed the highest mean concentration of 36.5 $\mu g\ l^{-1}$, which was followed by Kisumu Bay (station 1) with 26.5 $\mu g\ l^{-1}$. No significant difference was found among the stations.

4.3 PRIMARY PRODUCTIVITY

4.3.1 Seasonal Variation

Seasonal changes in the mean gross photosynthetic rates are shown in Fig. 18. The phytoplankton photosynthetic rates in the Wiman Gulf vary seasonally. During the present study the highest photosynthetic rate in the water column measured was 0.74 g $O_2\ m^{-3}\ h^{-1}$ in Nyakach Bay (station 5) in January, 1987.

There were two peaks of primary productivity in the Winam Gulf. The first peak was observed from June to August. Following this peak there were minor fluctuations until the period November to February when another peak was observed. Vertically, only one maximum existed in the water column throughout the study period. Photosynthetic activity usually declined with increase in depth below the maxima reaching very low values at a depth of 3 m. Depth distribution of primary productivity is shown in Figs. 19 - 27. The maximum hourly rate of gross photosynthesis

Fig. 17. Annual mean chlorophyll a concentrations at 0.5m depth at stations 1 to 5. Vertial bars represent standard deviation.

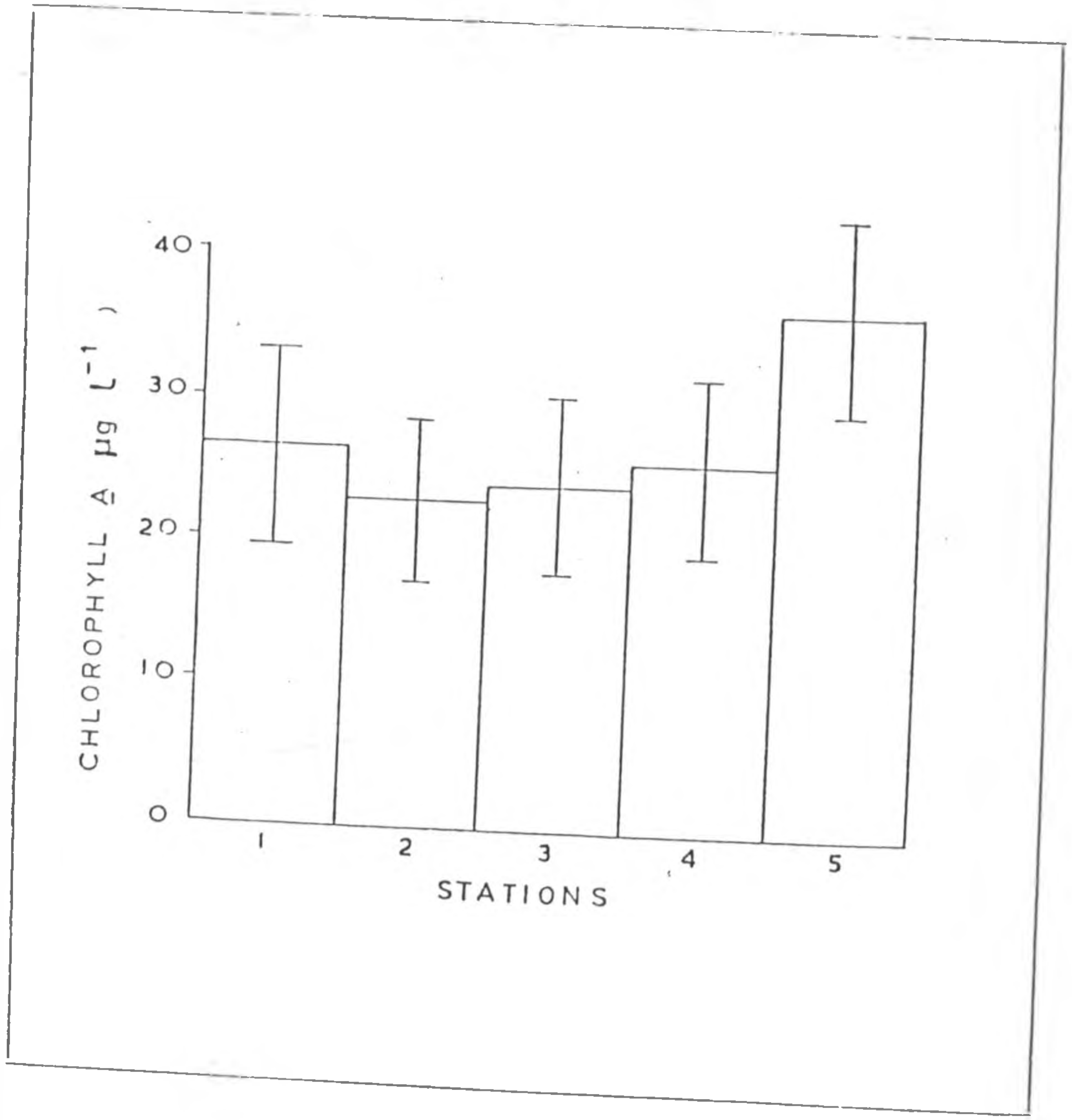


FIG. 17

Fig. 18. Seasonal variation in mean photosynthetic rates within the water column at stations 1 to 5.

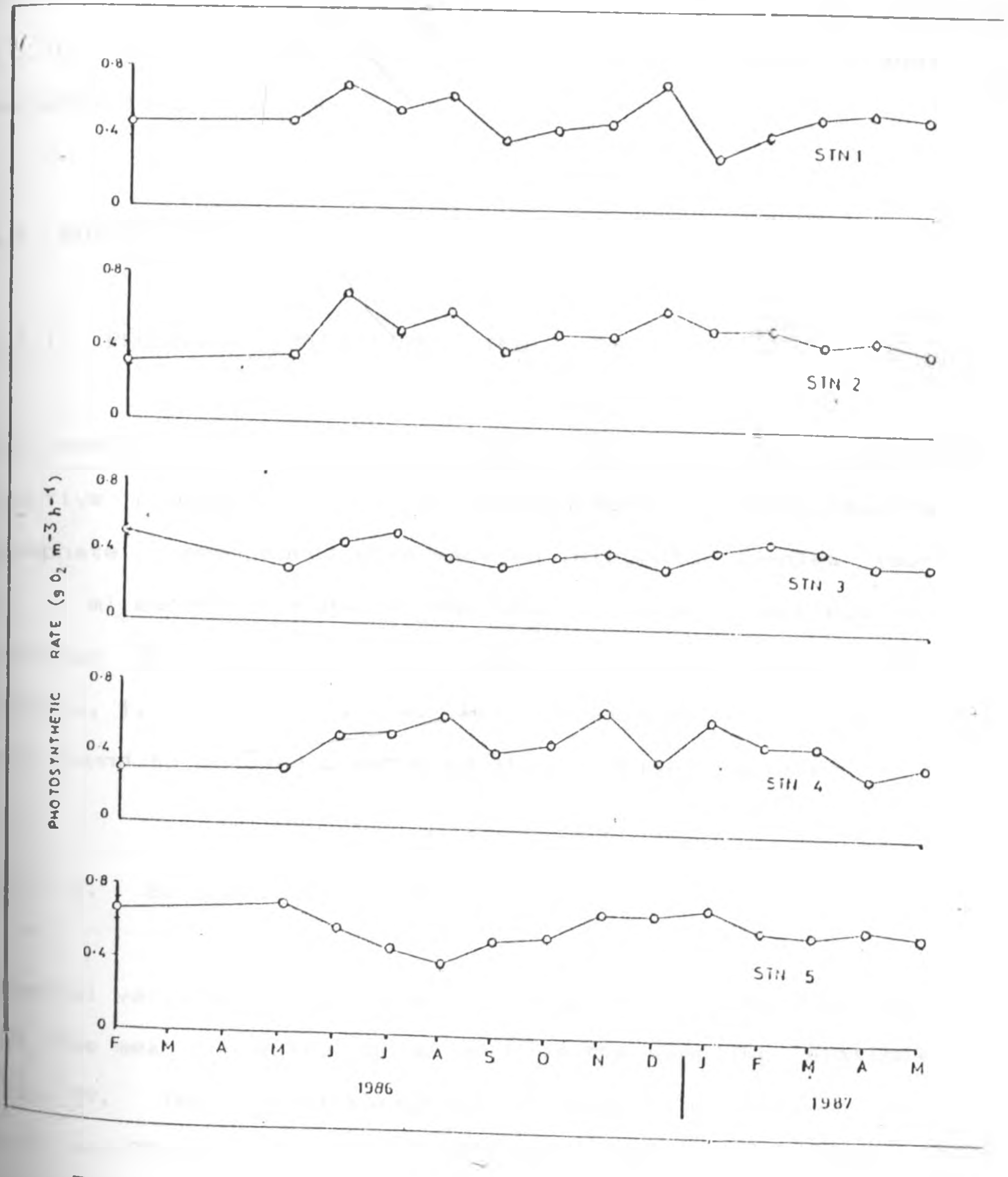

PHOTOSYNTHETIC RATE (g O2 m-3 h-1)
0·8
0·4
0
STN 1
STN 2
STN 3
STN 4
STN 5
F
M
A
M
J
J
A
S
O
N
D
J
F
M
A
M
1986
1987

FIG. 18

measured in the Winam Gulf was 1.2 g O_2 m^{-3} h^{-1} at 0.5 m at Nyakach Bay in January 1987 (Fig. 25), while the minimum was 0.18 g O_2 m^{-3} h^{-1} near the surface at station 3 (Ndere Island) in December 1986 (Fig. 24).

4.4 NUTRIENTS

4.4.1 PHOSPHATE - PHOSPHORUS (PO_4 - P)

The form of phosphorus investigated in this study was the soluble reactive phosphorus (SRP) or orthophosphate. Measurements of phosphate - phosphorus were made on integrated samples (surface to 3 m) except on 6 March 1987 when vertical distribution was measured at station 3. This time samples were taken from the surface, 1, 2 and 3 m depths. Horizontal and seasonal variations were found to be more pronounced than vertical variation.

4.4.1.1. Seasonal Variation

Seasonal variation of phosphate - phosphorus is shown in Fig. 28 and the mean concentration at each of the sampling stations in Fig. 29. The highest phosphate concentration measured in the Gulf was 34 µg PO_4 - P l^{-1} at Nyakach Bay in May, 1987 while the lowest was 2 µg PO_4 - P l^{-1} at Kisumu Bay in February, 1986. Nyakach Bay had the highest mean concentration of

Figs. 19-27. Profiles of photosynthtic rates in the winam Gulf during various months of the period of study. Values in paretheses (Figs. 20-27) represent daily areal rates in g O_2 $m^{-2}d^{-1}$. In Fig. 19 chlorophyll a values are shown in a histogram (inset). End of the curve concides with the bottom of the lake.

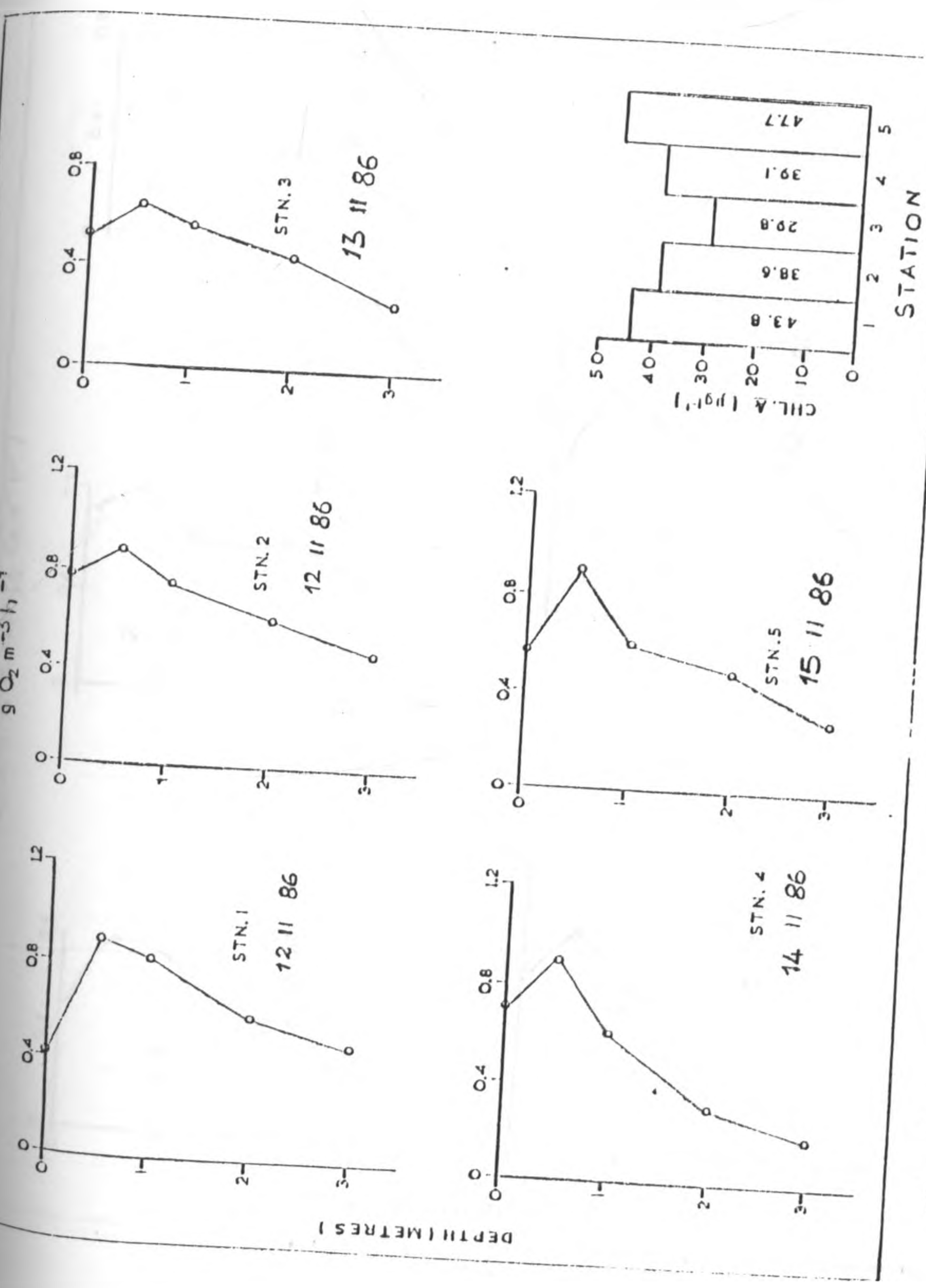

g O2 m-3 h-1
DEPTH (METRES)
STN. 1
12 11 86
STN. 2
12 11 86
STN. 3
13 11 86
STN. 4
14 11 86
STN. 5
15 11 86
0
0.4
0.8
1.2
0
1
2
3
CHL.A (µg l-1)
0
10
20
30
40
50
43.8
38.6
29.8
39.1
47.7
1
2
3
4
5
STATION

FIG. 19

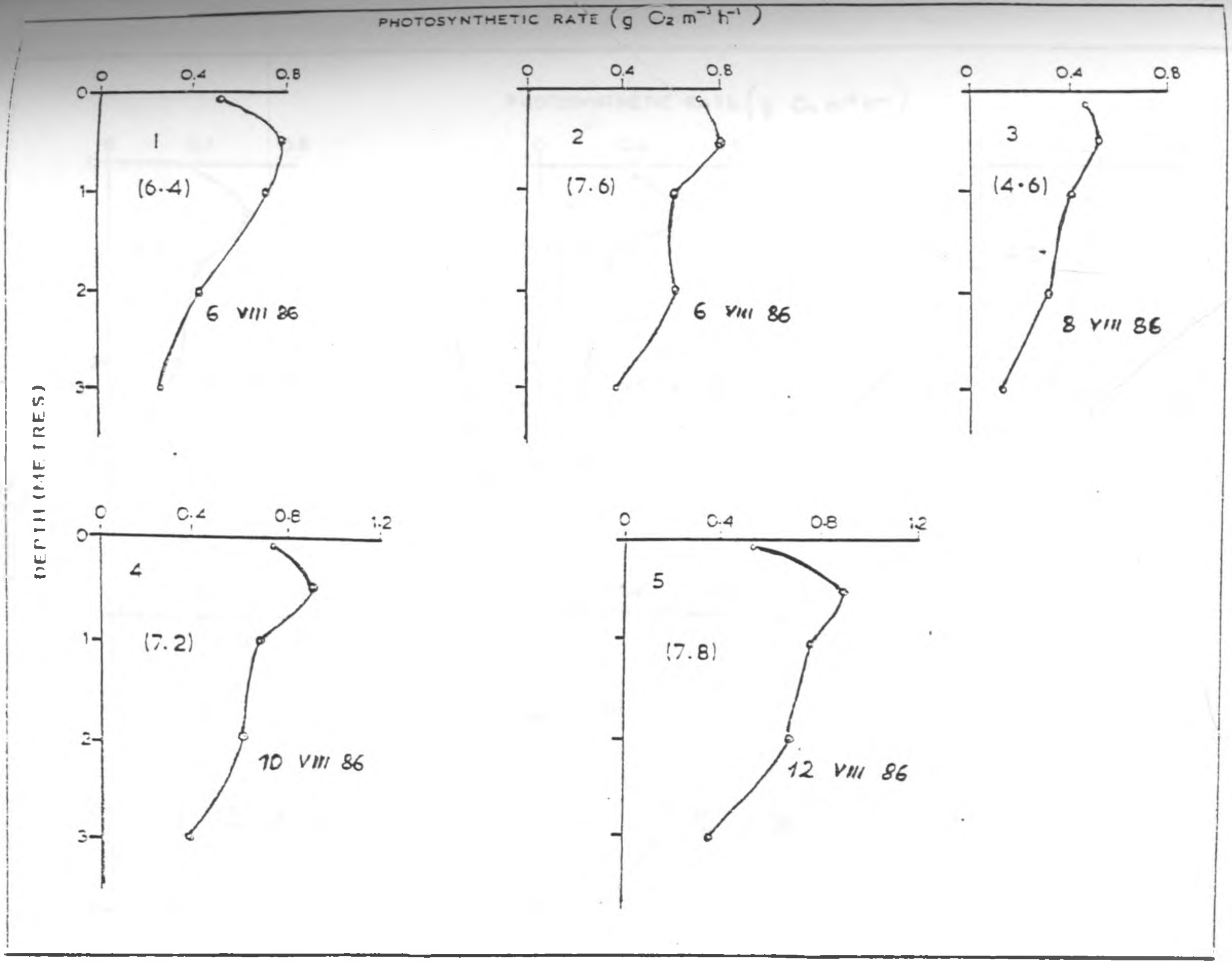

PHOTOSYNTHETIC RATE (g O2 m-3 h-1)
DEPTH (METRES)
0
0.4
0.8
1.2
1
2
3
1
(6.4)
6 VIII 86
2
(7.6)
6 VIII 86
3
(4.6)
8 VIII 86
4
(7.2)
10 VIII 86
5
(7.8)
12 VIII 86

FIG. 20

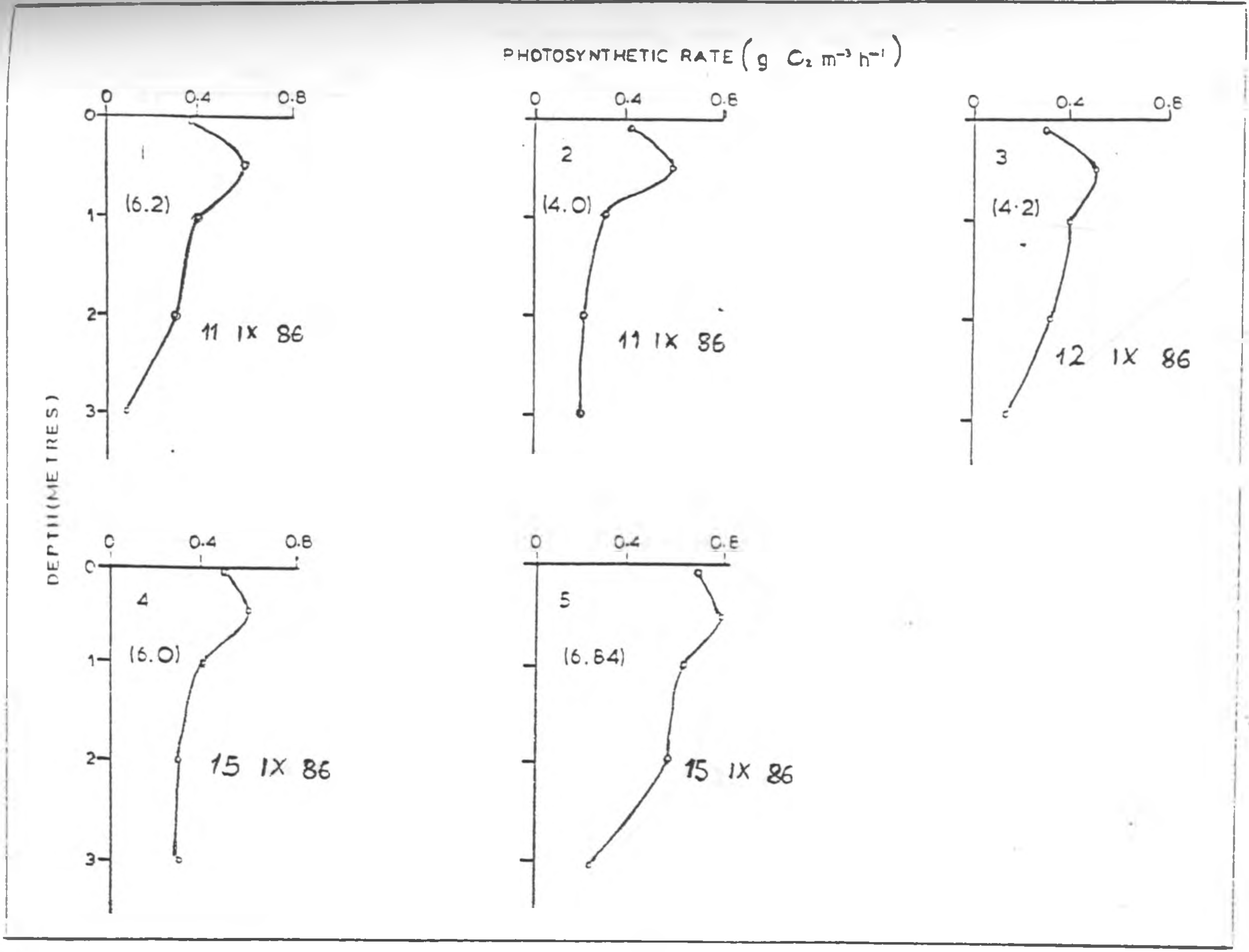

PHOTOSYNTHETIC RATE (g C₂ m⁻³ h⁻¹)
DEPTH (METRES)
0
0.4
0.8
0
1
2
3
1
(6.2)
11 IX 86
2
(4.0)
11 IX 86
3
(4·2)
12 IX 86
4
(6.0)
15 IX 86
5
(6.64)
15 IX 86

FIG. 21

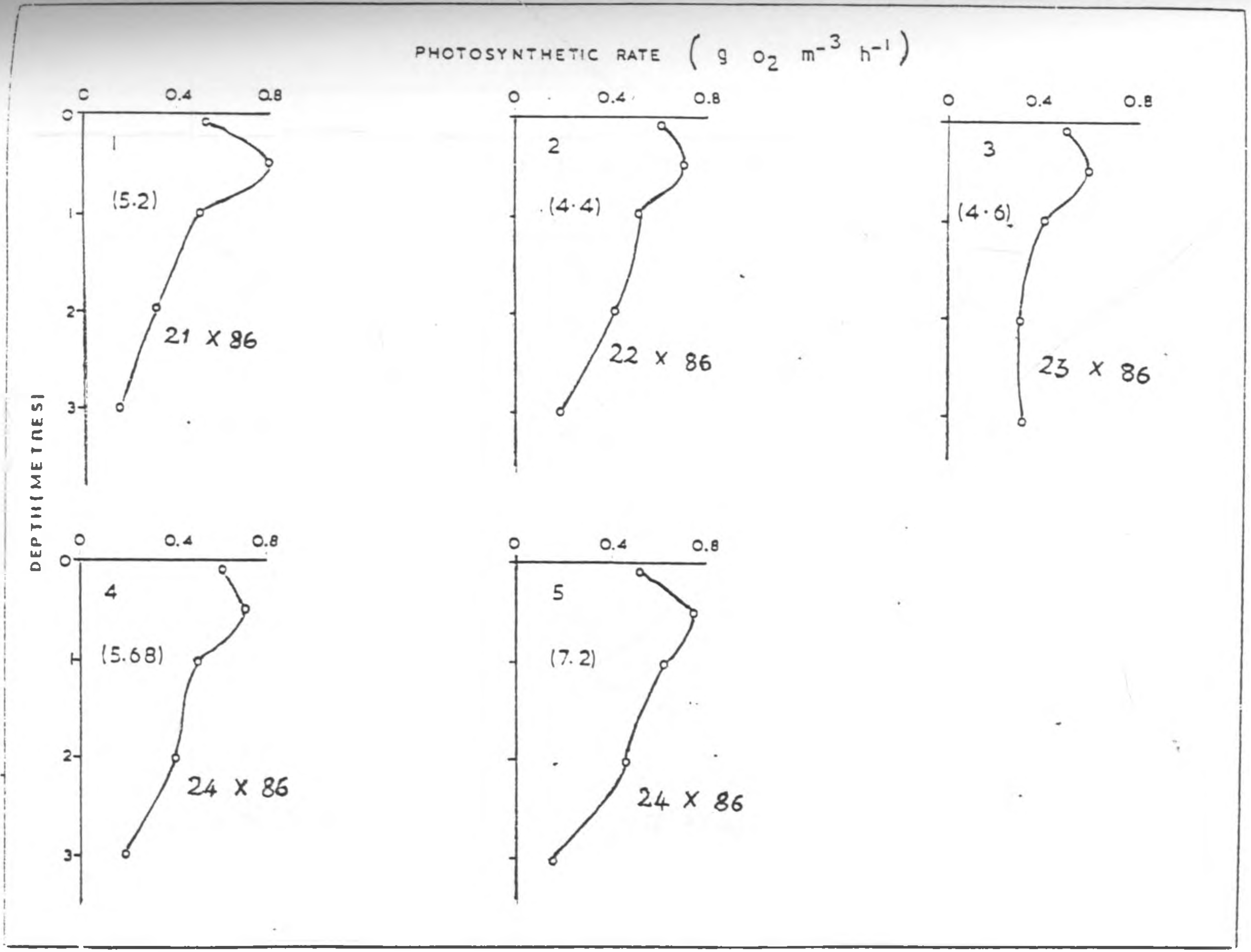

PHOTOSYNTHETIC RATE (g O2 m-3 h-1)
DEPTH (METRES)
0
0.4
0.8
0
1
2
3
1
(5.2)
21 X 86
2
(4·4)
22 X 86
3
(4·6)
23 X 86
4
(5.68)
24 X 86
5
(7.2)
24 X 86

FIG. 22

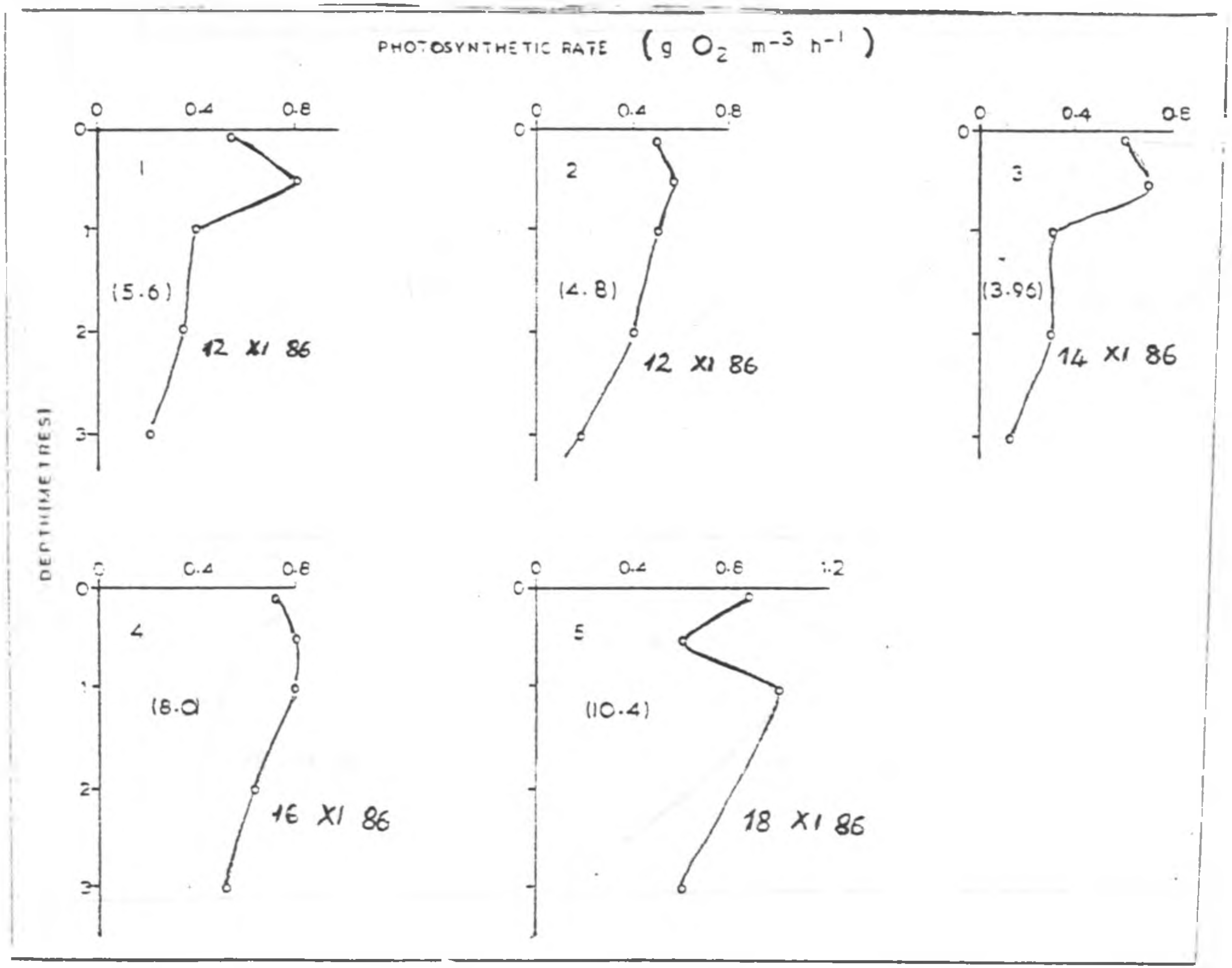

PHOTOSYNTHETIC RATE (g O$_2$ m^{-3} h^{-1})
DEPTH (METRES)
0
0.4
0.8
1.2
0
1
2
3
1
2
3
4
5
(5.6)
(4.8)
(3.96)
(8.0)
(10.4)
12 XI 86
12 XI 86
14 XI 86
16 XI 86
18 XI 86

FIG. 23

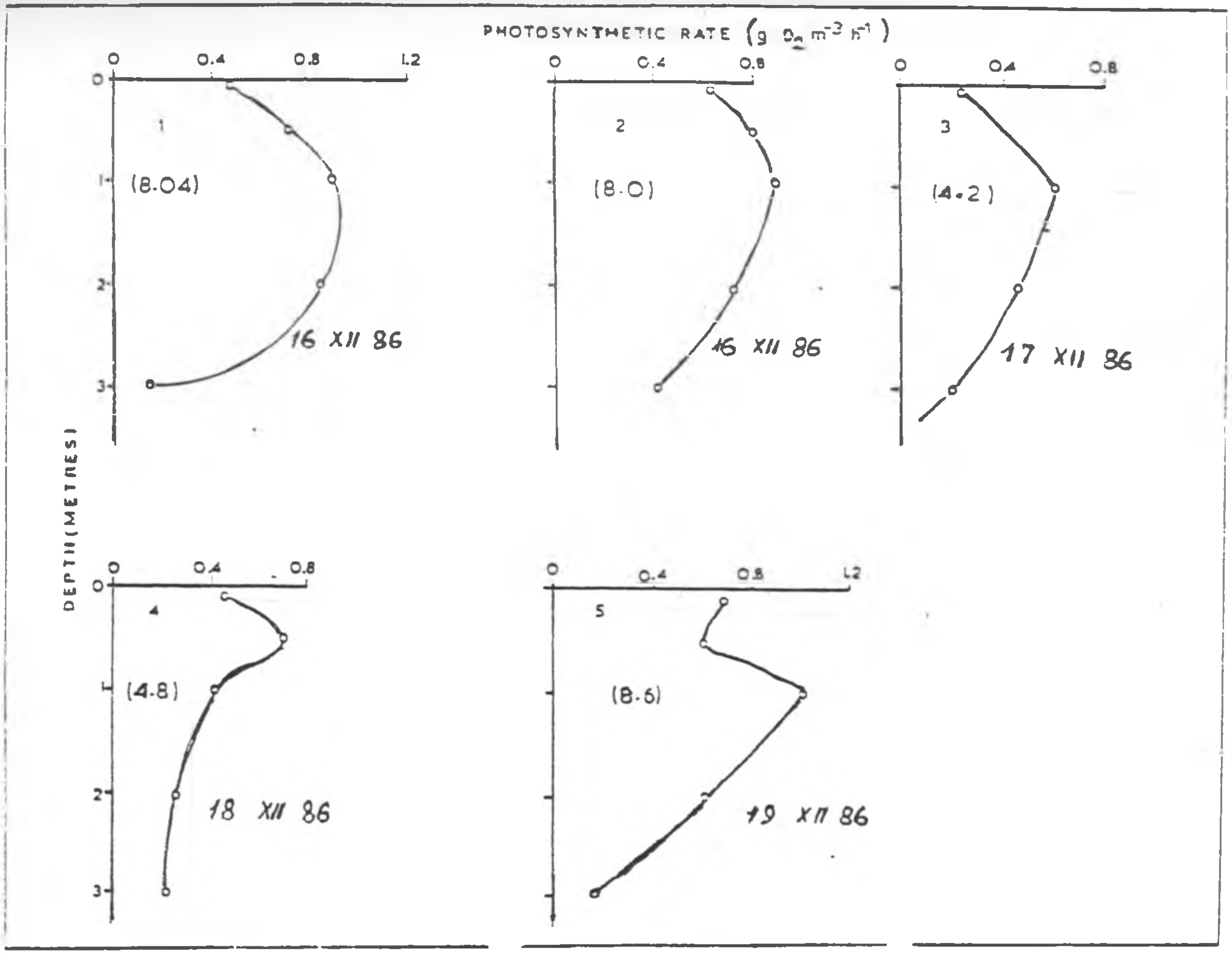

PHOTOSYNTHETIC RATE (g O2 m-3 h-1)
DEPTH (METRES)
0
0.4
0.8
1.2
0
1
2
3
1
(8.04)
16 XII 86
2
(8.0)
16 XII 86
3
(4.2)
17 XII 86
4
(4.8)
18 XII 86
5
(8.6)
19 XII 86

FIG. 24

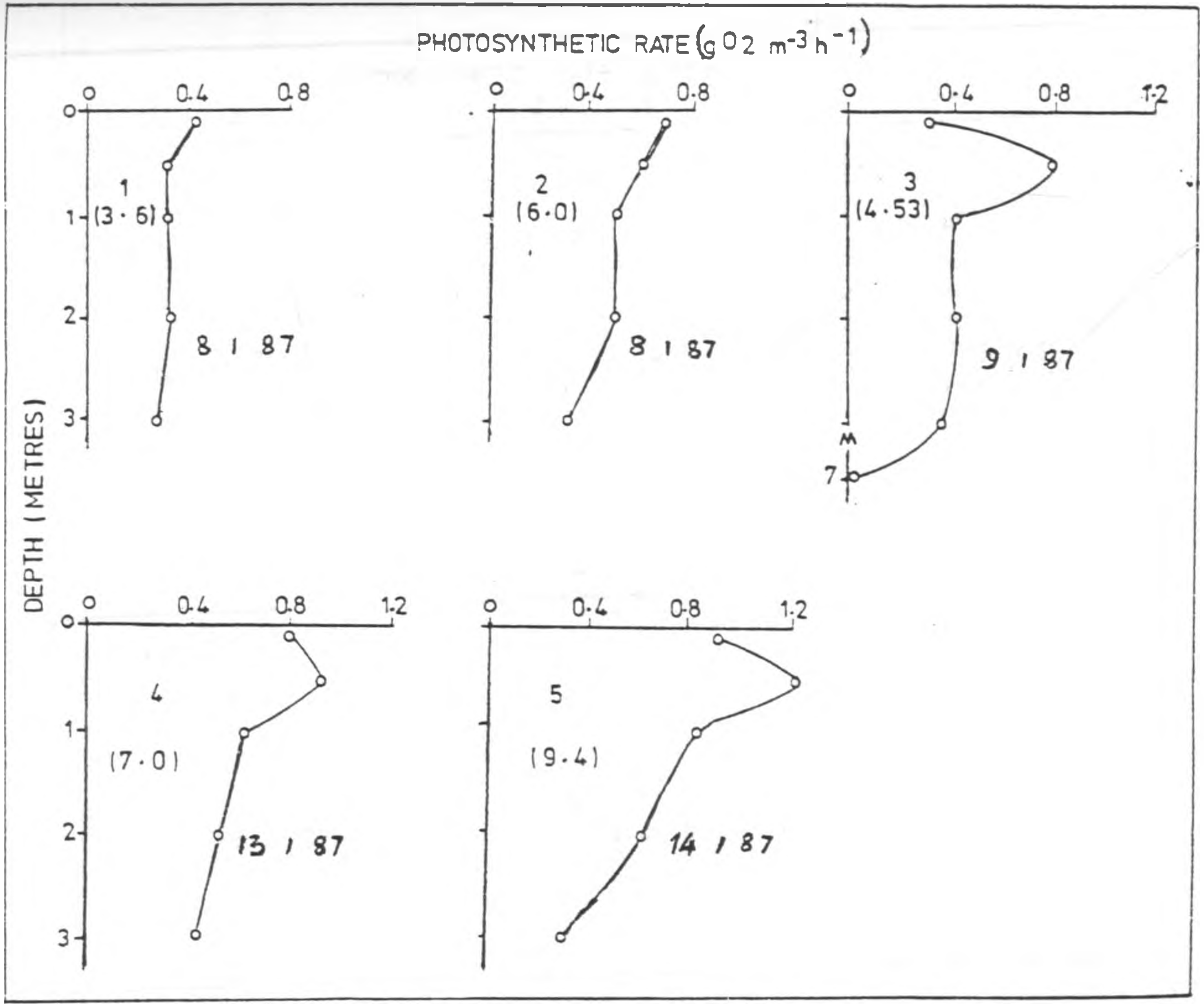

PHOTOSYNTHETIC RATE (g O2 m-3 h-1)
DEPTH (METRES)
0
0.4
0.8
1.2
0
1
2
3
7
1
(3·6)
8 1 87
2
(6·0)
8 1 87
3
(4·53)
9 1 87
4
(7·0)
13 1 87
5
(9·4)
14 1 87

FIG. 25

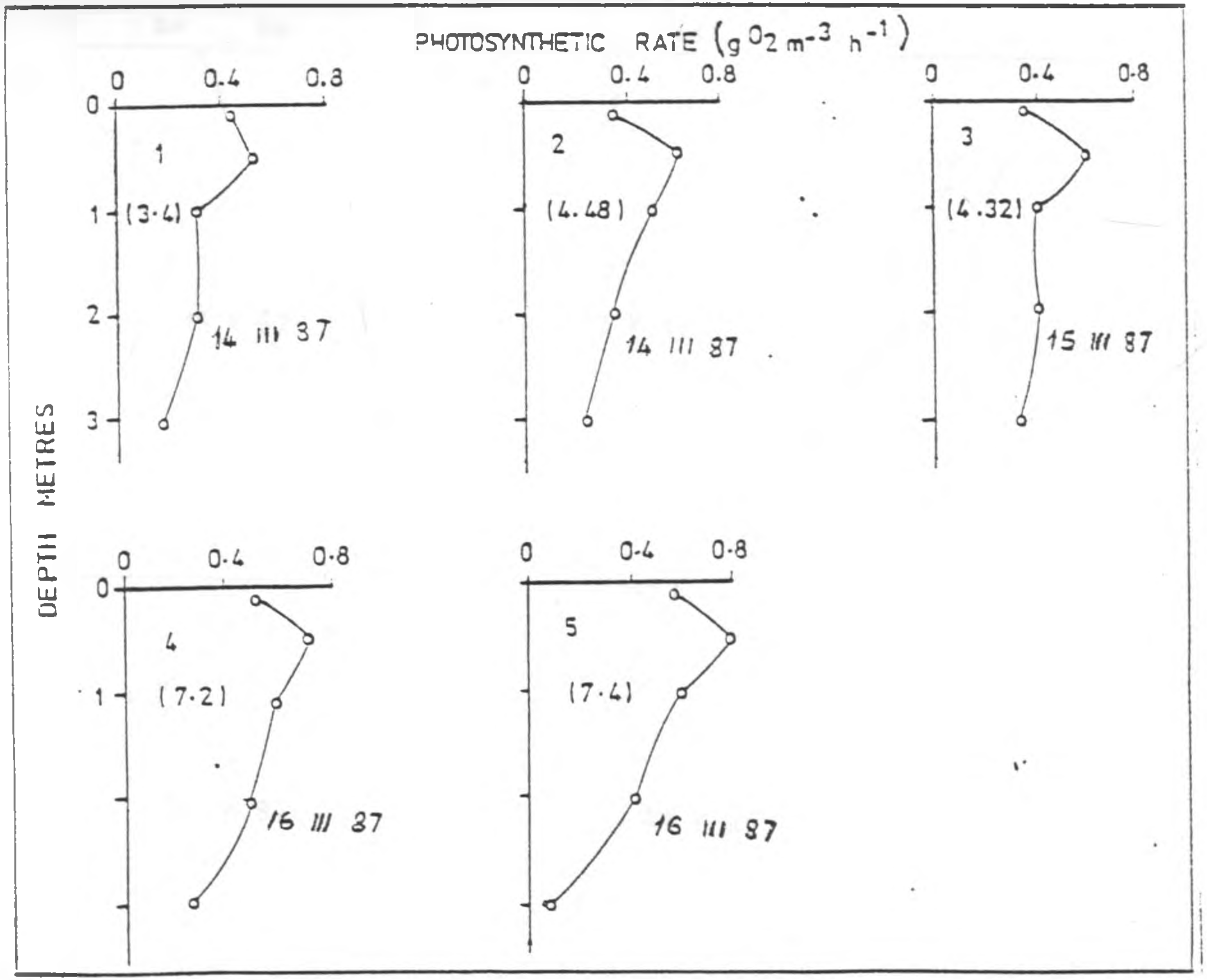
PHOTOSYNTHETIC RATE ($g\,O_2\,m^{-3}\,h^{-1}$)
DEPTH METRES
0
0.4
0.8
0
1
2
3
1
(3·4)
14 III 87
2
(4.48)
14 III 87
3
(4.32)
15 III 87
4
(7·2)
16 III 87
5
(7·4)
16 III 87

FIG. 26

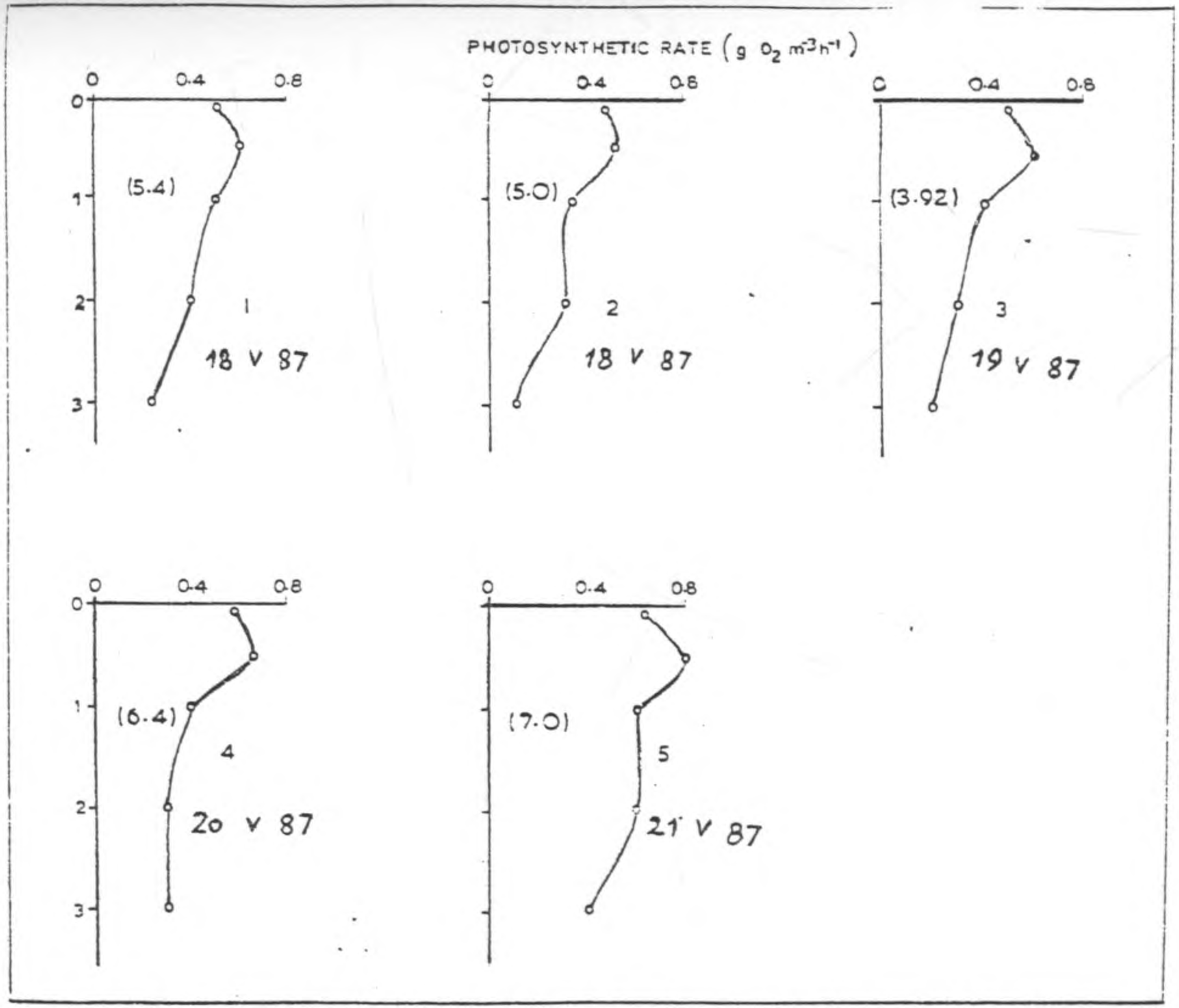

PHOTOSYNTHETIC RATE (g O2 m-3 h-1)
0
0.4
0.8
0
1
2
3
(5.4)
1
18 V 87
(5.0)
2
18 V 87
(3.92)
3
19 V 87
(6.4)
4
20 V 87
(7.0)
5
21 V 87

FIG. 27

Fig. 28. Seasonal variation in phosphate - phosphorus and nitrate - nitrogen at stations 1 to 5. Dashed lines indicate a period during which no data were collected.

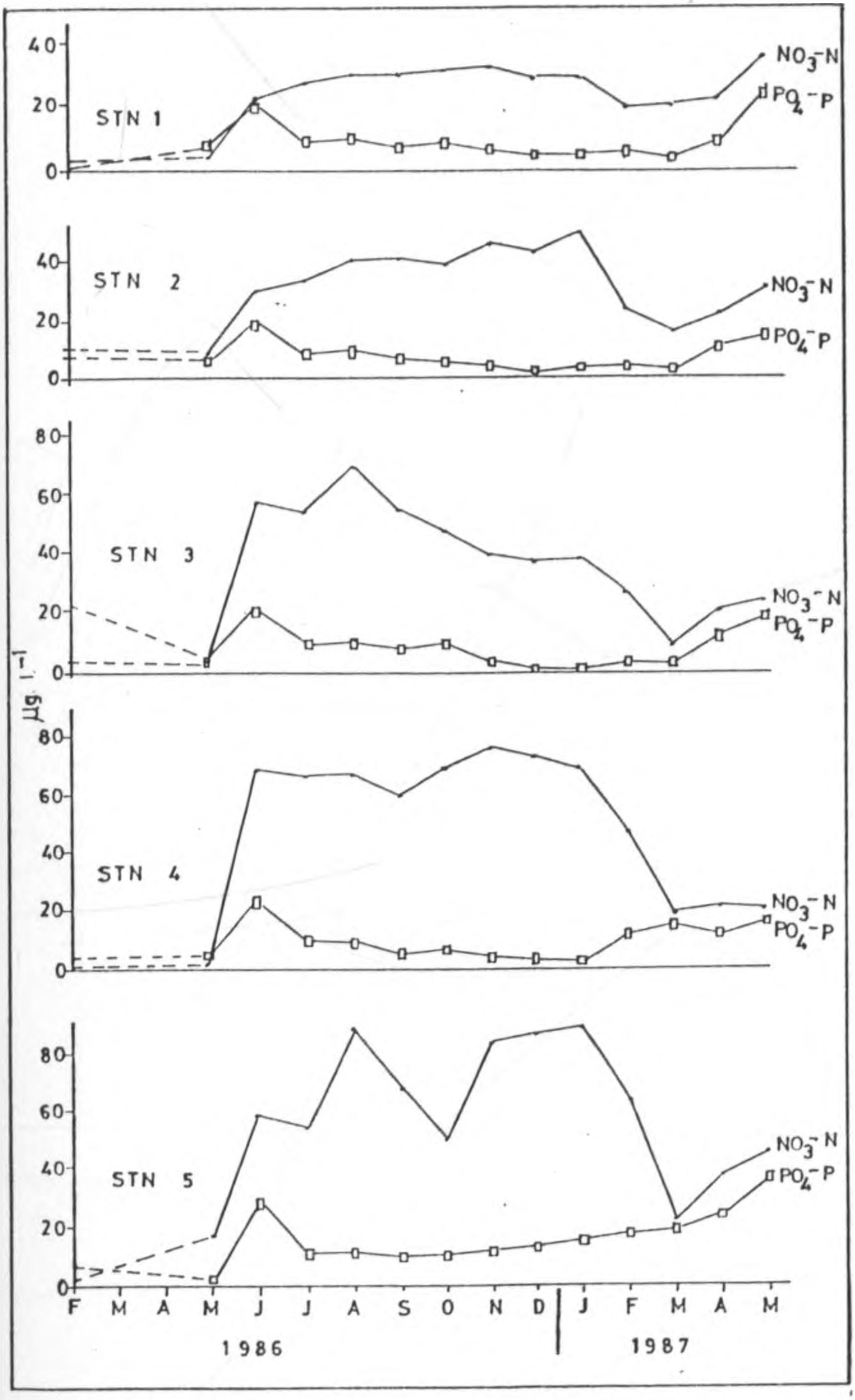

STN 1
STN 2
STN 3
STN 4
STN 5
NO_3^--N
PO_4^--P
μg l⁻¹
0
20
40
60
80
F
M
A
M
J
J
A
S
O
N
D
J
F
M
A
M
1986
1987

FIG. 28

Fig. 29. Mean annual concentrations of PO_4 - P at stations 1 to 5. Vertical bars represent standard deviation.

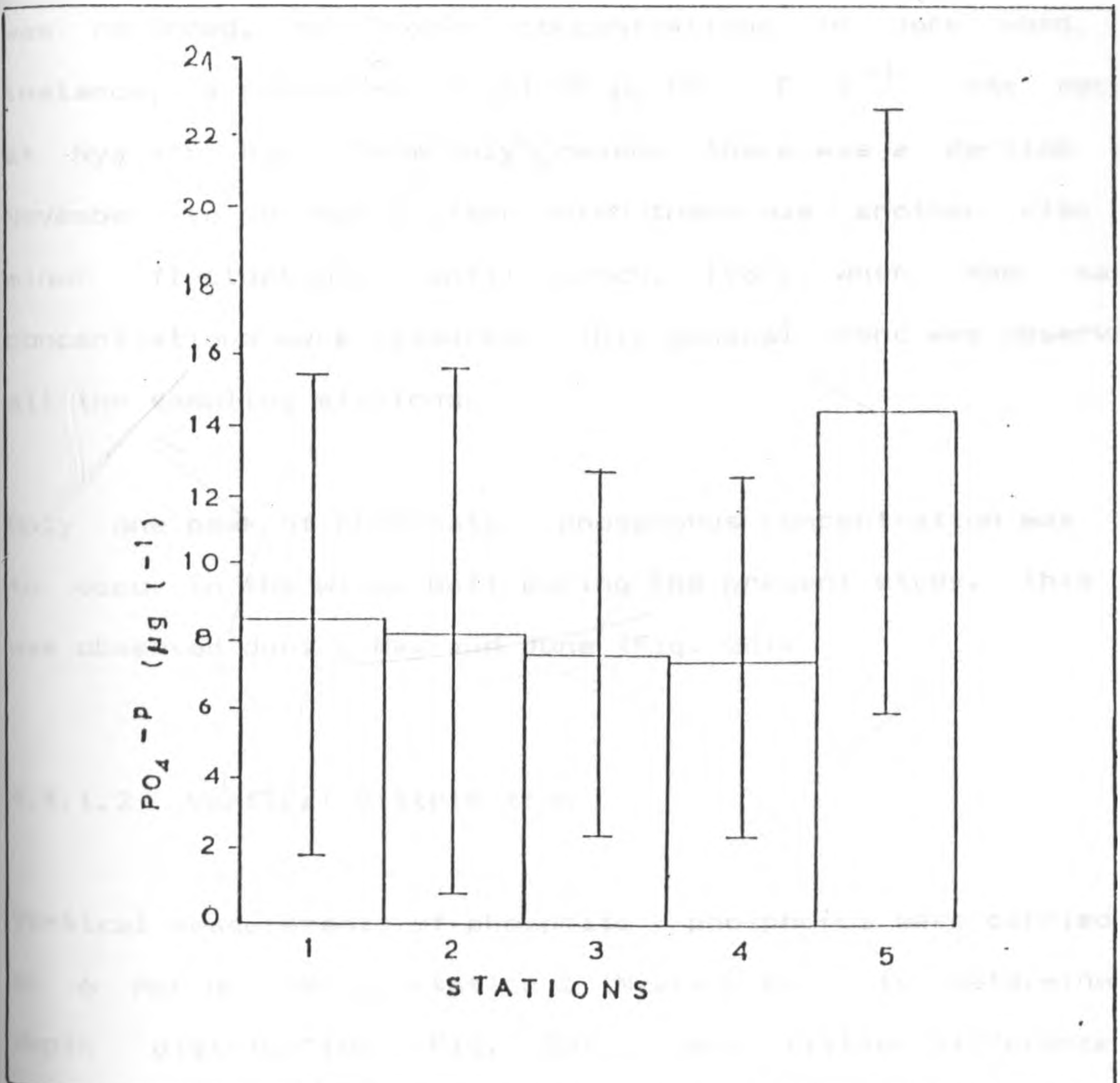


FIG. 29

phosphate-phosphorus in the Gulf (Fig. 29). Mean concentration here during the whole period of study was 14.6 µg l^{-1}. Station 4 had the lowest mean concentration of 7.4 µg l^{-1} Phosphate - phosphorus concentration in the Winam Gulf showed a general rise from February, 1986 when the minimum concentration was recorded, to higher concentrations in June when, for instance, a concentration of 28 µg PO - P l^{-1} was recorded at Nyakach Bay. From July onwards, there was a decline until November to December after which there was another rise with minor fluctuations until March, 1987, when the maximum concentrations were measured. This general trend was observed at all the sampling stations.

Only one peak of phosphate - phosphorus concentration was found to occur in the Winam Gulf during the present study. This peak was observed during May and June (Fig. 28).

4.4.1.2 Vertical Distribution

Vertical measurements of phosphate - phosphorus were carried out on 6 March, 1987 at station 5 (Nyakach Bay) to determine the depth distribution (Fig. 30). Very little difference in concentration at various depths was found. A value of 11.4 µg PO_4 - P l^{-1} was measured at the surface. At the 1 m depth the concentration decreased slightly to 11.2 µg l^{-1}.

phosphate-phosphorus in the Gulf (Fig. 29). Mean concentration here during the whole period of study was 14.6 µg l^{-1}. Station 4 had the lowest mean concentration of 7.4 µg l^{-1} Phosphate - phosphorus concentration in the Winam Gulf showed a general rise from February, 1986 when the minimum concentration was recorded, to higher concentrations in June when, for instance, a concentration of 28 µg PO - P l^{-1} was recorded at Nyakach Bay. From July onwards, there was a decline until November to December after which there was another rise with minor fluctuations until March, 1987, when the maximum concentrations were measured. This general trend was observed at all the sampling stations.

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4.4.1.2 Vertical Distribution

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Fig. 30. Vertical distribution of PO_4 - P in the water column at station 5 on 6 March 1987.

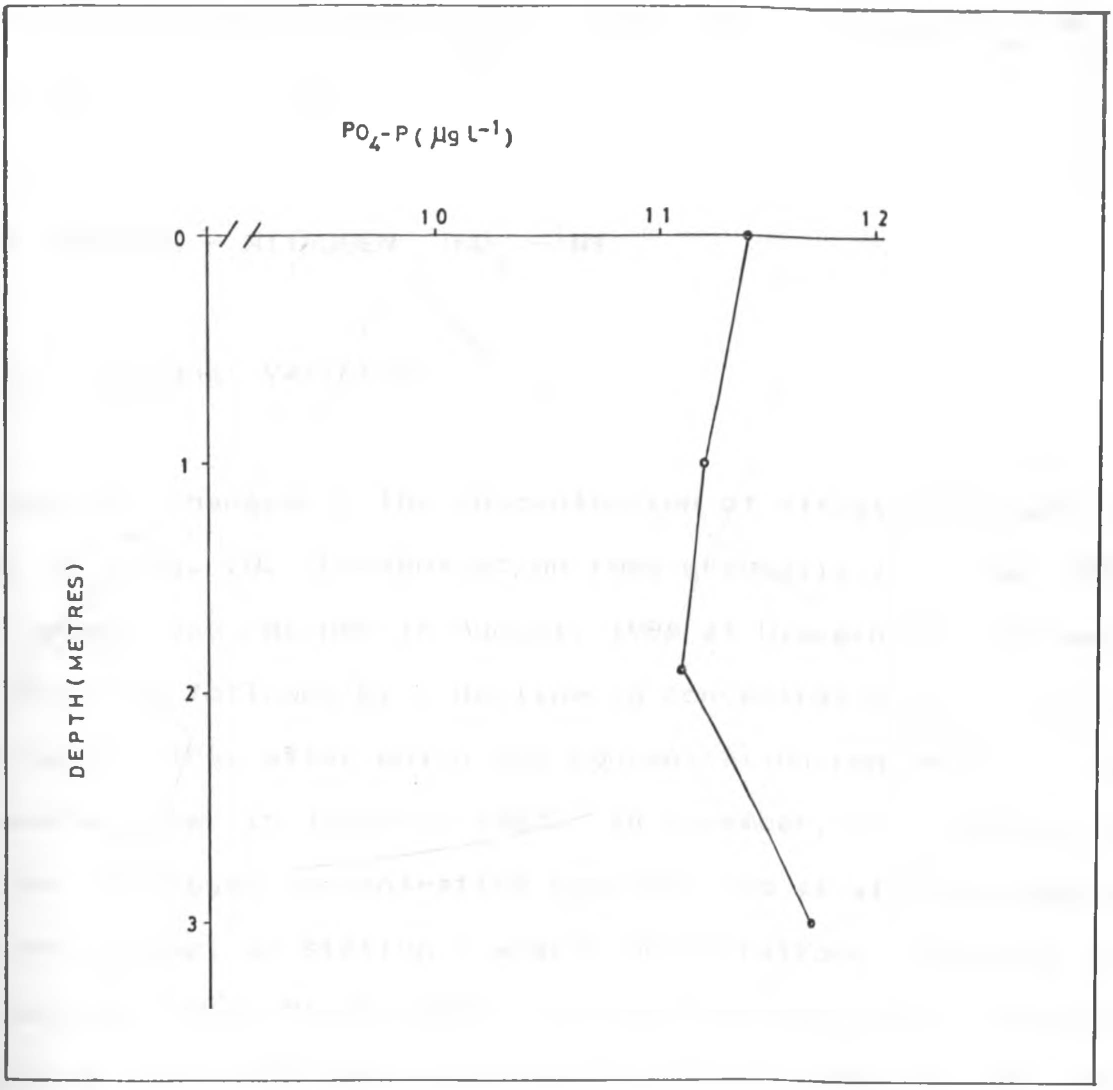


FIG. 30

The highest of 11.7 $\mu g\ PO_4 - P\ l^{-1}$ was measured at the 3 m depth, which was near the bottom. Thus the difference between surface and bottom concentrations was only 0.3 $\mu g\ PO_4 - P\ l$ (Fig. 30).

4.4.2 NITRATE - NITROGEN ($NO_3 - N$)

4.4.2.1 Seasonal Variation

The seasonal changes in the concentration of nitrate-nitrogen are shown in Fig. 28. Concentration rose gradually from May 1986 until a peak was reached in August, 1986 at Nyakach Bay (station 5). This was followed by a decline in concentration to a low one in October, 1986, after which the concentration continued to rise to another peak in January, 1987. In November, an increase in nitrate - nitrogen concentration was observed at all the sampling stations except at station 3 where concentrations remained low and declined until March, 1987. In April and May 1987, there was a rise in concentrations reaching levels 3 x those of the same month (May) in the previous year.

Two peaks of nitrate - nitrogen were found to exist during the period of study in the Winam Gulf. The larger peak occurred in June - August (cf. $PO_4 - P$, Fig. 28). The second and lesser peak occurred in November to January. It was during the first peak that the maximum concentration of 85 $\mu g\ NO_3 - N\ l^{-1}$ was

Fig. 31. Mean annual concentration of NO_3 - N at stations 1 to 5. Vertical bars represent standard deviation.

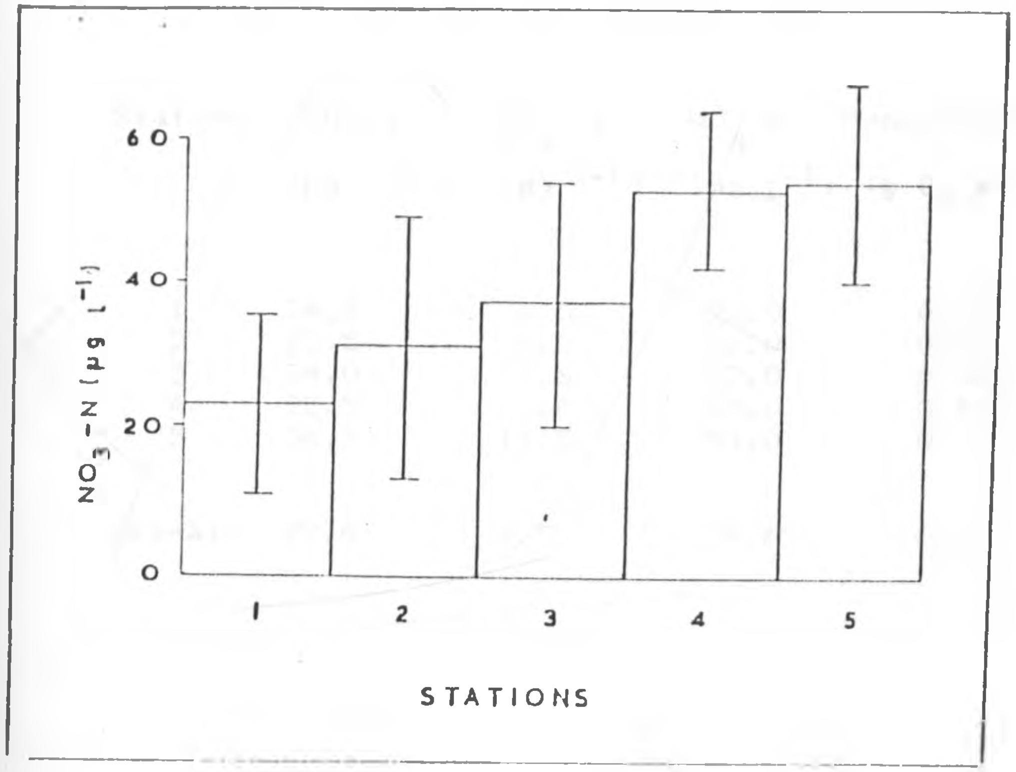


FIG. 31

Table 5. Annual mean chlorophyll *a* (chl.*a*), pgosphate - phosphorus (PO_4 - P) and nitrate - nitrogen (NO_3 - N) concentrations and productivity at the 0.5m depth at the five sampling stations of the Winam Gulf. the overall mean represents the mean for the study area.

Station	Chl.a ($\mu g\ l^{-1}$)	PO_4 - p ($\mu g\ l^{-1}$)	NO_3-N ($\mu g\ l^{-1}$)	Productivity ($g\ O_2\ m^{-3}\ h^{-1}$)
1	26.5	8.6	23.0	0.53
2	22.5	8.2	31.0	0.51
3	24.0	7.6	37.0	0.44
4	25.5	7.4	53.0	0.49
5	36.5	14.5	54.0	0.74
Overall	27.0	9.3	39.6	0.54

recorded at Nyakach Bay (station 5). The minimum concentration of 2.5 µg NO_3 - N l^{-1} was recorded at Kisumu Bay (station 1) in February, 1986.

Mean annual concentrations of nitrate - nitrogen are shown in Fig. 31. Mean concentration was lowest at Kisumu Bay (23 ± 13 µg NO_3 - N l^{-1}) and increased at stations 2, 3, 4 and 5. Nyakach Bay (station 5) near the mouth of River Nyando, showed the highest mean annual concentration of 54 ± 14 µg NO_3 - N l^{-1} . There was no significant difference among the sampling stations.

4.4.2.2 Vertical Distribution

The vertical distribution of nitrate - nitrogen was investigated at Nyakach Bay (station 5) on 6 March, 1986. Results are shown in Fig. 32. Concentration was found to be higher in the lower water layer than in the upper one. The surface concentration was 10.6 µg NO_3 - N l^{-1} . It increased to 13 µg l^{-1} at 0.5 m and at the 1 m depth fell to 6 µg l^{-1} .

Below this depth, the concentration increased markedly reaching a value of 18.6 µg l^{-1} at 3 m near the bottom of the water column.

Table 6. Mean daily productivity (g O_2 m^{-2} d^{-1}) in the Winam Gulf during various months and at different sampling stations.
$\bar{x}$ = mean and SD = standard deviation.

STATIONS

Month	1	2	3	4	5	Gulf Values	
						$\bar{X}$	SD
Jan	3.60	6.00	4.52	7.00	0.40	6.24	2.16
Mar	3.40	4.48	4.32	7.20	7.40	5.34	1.83
May	5.40	5.00	3.92	6.40	7.00	5.53	1.20
Aug	6.40	7.60	4.60	7.20	7.80	6.72	1.30
Sep.	6.20	4.00	4.20	6.00	6.84	5.45	1.27
Oct.	5.20	4.40	4.60	5.68	7.20	5.41	1.11
Nov.	5.60	4.80	3.96	8.00	10.40	6.55	2.63
Dec.	8.04	8.00	4.12	4.80	8.60	6.71	2.08
Station Values							
$\bar{X}$	5.48	5.53	4.28	6.53	8.08		
SD	1.50	1.51	0.27	1.02	1.27		

Fig. 32. Vertical distribution of $NO_3 - N$ in the water at station 5. On 6 March, 1987.

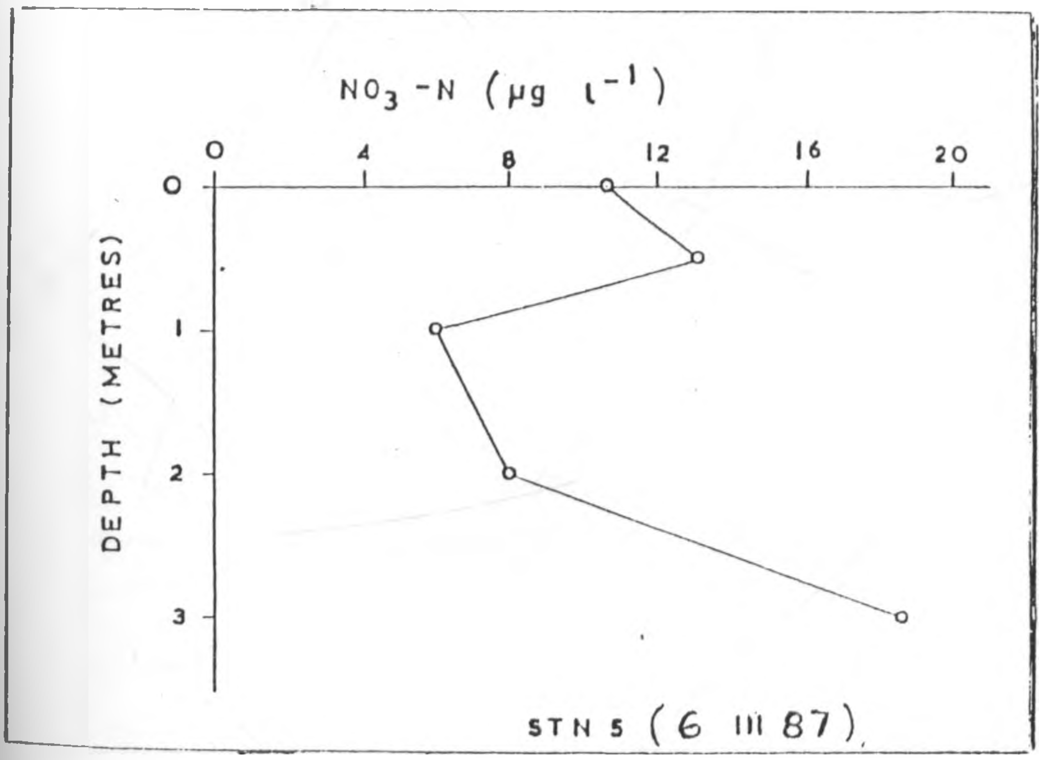


FIG. 32

Fig. 33. Depth distribution of photosynthetic rate per unit chlorophyll a at various stations and dates in the Winam Gulf during the study period.

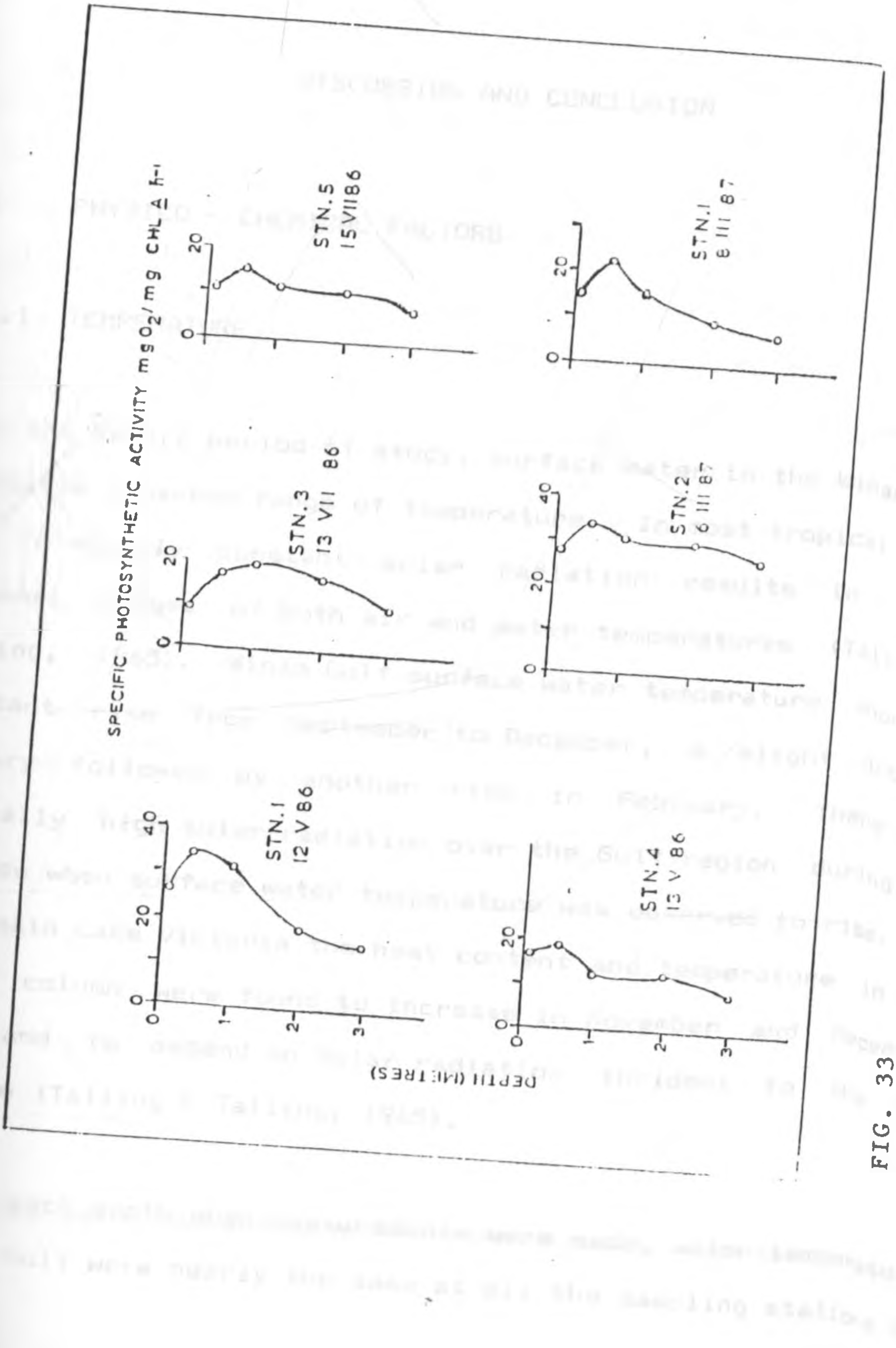

SPECIFIC PHOTOSYNTHETIC ACTIVITY mg O2/ mg CHL A h-1
DEPTH (METRES)
STN.1
12 V 86
STN.3
13 VII 86
STN.5
15 VII 86
STN.4
13 V 86
STN.2
6 III 87
STN.1
6 III 87
0
20
40
0
1
2
3

FIG. 33

CHAPTER 5

DISCUSSION AND CONCLUSION

5.1 PHYSICO - CHEMICAL FACTORS

5.1.1 TEMPERATURE

Over the entire period of study, surface water in the Winam Gulf exhibited a narrow range of temperature. In most tropical lakes, the relatively constant solar radiation results in narrow seasonal ranges of both air and water temperatures (Talling & Talling, 1965). Winam Gulf surface water temperature showed a constant rise from September to December, a slight drop in January followed by another rise in February. There was generally high solar radiation over the Gulf region during the periods when surface water temperature was observed to rise. In the main Lake Victoria the heat content and temperature in the water column were found to increase in November and December, 1964 and to depend on Solar radiation incident to the lake surface (Talling & Talling, 1965).

During each month when measurements were made, water temperatures in the Gulf were nearly the same at all the sampling stations but showed a tendency to be slightly higher in the more offshore stations e.g. stations 2 and 3 where there was no river influence. Temperatures in the more enclosed stations tended to be slightly lower, e.g. station 5. Lower temperatures were, as would be expected, measured on days with reduced solar radiation. While stations 2 and 3 have no influence from rivers, the rest of the stations have some influence by the inflowing streams and rivers that enter the Gulf. The most marked example of this influence by a river on water temperatures was that found at Nyakach Bay. Water temperatures were generally lower at this station during the study period. It is through this bay that one of the major rivers, River Nyando, enters the Winam Gulf. Having its source in the highlands the waters of this river are much colder (21 ^{0}C during the day at the mouth) than the lake water. This, combined with the relatively large volume of the river water affects the water temperature of the bay by lowering it. River Sondu with similar temperature characteristics enters the Gulf only approximately 2 km to the south of the Bay. Winds blowing from the south-east bring waters of River Sondu into Nyakach Bay thus lowering the temperatures further.

Unlike Nyakach Bay, Kisumu Bay (station 1) receives water of a different quality. River Kasat empties into Kisumu Bay in the eastern end. It is the receiving body for effluents from the Kenya Breweries at Kisumu, the Kisumu Cotton Mill and the Kisumu

Municipality sewage treatment lagoons. The temperatures of this stream are usually as high as, and sometimes higher than, those of the lake water. Thus the stream has the effect of raising the water temperatures in this bay. Nyamu (1986) found mean temperatures in Kisumu Bay to be highest near the mouth of River Kasat.

Temperature profiles show a lack of any strong thermal stratification in the Winam Gulf. This is mainly due to the general shallowness of the Gulf which allows complete vertical mixing of the water by winds blowing on the lake surface. Stratification was observed to be lost with southwesterly winds at a deep station (Z_m = 11.8 m) south of Uyoma (Worthington, 1930). Therefore, much less or lack of stratification would be expected in the shallower area of the present study. During the period of this study, wind speeds ranged from 3 to 11 Knots during the day when measurements were made. These speeds were found to be high enough to break the thermal stratification.

The vertical mixing of shallow water and thermal stratification of deep water are shown by the comparison of temperature profiles at Kisumu Bay (Z_m = 3 m) and Rusinga Channel (Z_m = 46 m). While there was complete mixing at Kisumu Bay causing an isothermal condition, the water at Rusinga Channel was stratified into three distinct layers. Sometimes superficial temperature gradients were encountered in the Winam Gulf. These may vary with solar heating and are short-lived (Newell, 1960) or may be as a result of cold river water flowing outward toward the lake without completely mixing with the warmer lake water. This explains the thermal stratification observed at Nyakach Bay on 15 July, 1986 (Fig. 6 B).

A comparison between the Winam Gulf and Lake George, Uganda, shows that although shallower, the latter exhibits a stronger thermal stratification. A temperature difference of 10 ^{0}C between the surface and bottom water was found to exist but was broken by light winds in the late afternoon (Ganf & Horne, 1973).

The diurnal temperature changes monitored at Nyakach Bay on 29 and 30 December 1986 (Fig. 8) show that the seasonal range of water temperature is less than the diurnal range. A drop in the air temperature by about 5 ^{0}C at 1300 h due to a cloud, was found to cause water temperature to drop by 1.6 ^{0}C within an hour. The highest water temperature was recorded at 1200 h on 29 December, 1986 the time of maximum solar radiation of the day.

This, together with the effect of the cloud cover on water temperature discussed above, shows the marked influence of incident solar radiation on water temperatures.

The rise in water temperature observed at 1700 h on 29 December, 1986 was caused by a change in the direction of the water movement, with winds blowing eastwards into the bay thus bringing warmer lake water into the bay, and the disappearance of the cloud cover over the lake. This allowed increased solar radiation over the lake surface. The drop in water temperature after 2000 h until 0500 h on 30 December, 1986 was mainly due to falling air temperatures at night. The further drop at 0600 h and 0700 h was caused by an increase in wind speed over the lake. Subsequently, however, the effect of increasing incident radiation caused a progressive rise in water temperature.

5.1.2 DISSOLVED OXYGEN

Although absolute values of dissolved oxygen concentrations in the Winam Gulf surface water showed a range of 4.3 mg O_2 l^{-1}, mean concentrations varied very little during the present study period with both the maximum level of oxygen concentration and the highest mean concentration being recorded at Nyakach Bay. This relatively high concentration of dissolved oxygen was probably caused by high phytoplankton densities accompanied by high photosynthetic rates at this station during the study period. This is shown by the considerably higher biomass and productivity recorded here than at any other sampling station.

The high phytoplankton biomass and primary productivity are the result of increased nutrient inputs into the bay through the inflowing River Nyando especially during the rainy season. The general shallowness of the bay also renders it prone to stirring of the water by winds causing nutrients to be released from the sediments into the water thus leading to increased productivity (cf. Symoens *et al.* 1981). This area is influenced by River Kasat which carries industrial and domestic effluents especially from the Kisumu Municipality sewage lagoons. The stream itself has a very low oxygen content (0.8 - 3 mg l^{-1} approximately 500 m upstream from the mouth). The introduction of organic matter through this stream lowers the oxygen content of the water in this bay due to the consumption of oxygen during decomposition. To the south - east end of the Bay is the Kisumu Municipality Abattoir located only about 10 m from the lake shore. Large amounts of animal gut contents and blood find their way into the lake directly each day. The numerous motor vehicle workshops and open air garages within Kisumu Municipality also play a part in the reduction of oxygen in Kisumu Bay. With the blocked storm drains in the town, engine oil emanating from these workshops and garages is washed into the lake during the rains. Numerous and vast patches of oil films are a common feature in Kisumu Bay especially during the rainy season. Such films reduce the aeration process of the water and thus lower oxygen content. Servicing and refilling of ships and boats with engine oil and fuel at the Kisumu Harbour have the same effect. Low oxygen content in Kisumu Bay has also been reported near areas where cars are washed along the shores of the lake (Nyamu, 1986).

Dissolved oxygen concentration in the Gulf reached maximum levels near the surface. This would be expected due to higher oxygenation by atmospheric air. Concentrations were highest around 1500 h. This corresponded with the period of highest photosynthetic rates. Concentrations were fairly homogeneous throughout the water column. Even at the considerably deeper station at Rusinga Channel (Station H) there was some homogeneity in the upper 2 m layer and again in the 2.5 - 11. 0 m layer. The fact that even at the 30 m depth the oxygen content of the water was as high as 5.2 mg l^{-1} is an indication that the water is well oxygenated. The good oxygenation of the water from top to bottom has been reported as further evidence for frequent mixing in the Winam Gulf (Melack, 1979a).

A less pronounced oxygen stratification was found at Nyakach Bay on 15 July, 1986, with concentration falling by 2.8 mg l^{-1} from the surface to 3 m. The high oxygen content at the surface was caused by the photosynthetic activity of the Cyanophyte, Microcystis aeruginosa Kutzing. which was in bloom. Due to the self shading effect of this algal species there was reduced photosynthetic activity in the lower water layer thus causing a reduction in oxygen concentration.

Foxall et al. (1985) found dissolved oxygen to be generally uniformly distributed in the water column in the Winam Gulf. They found concentrations to range between 6.4 to 8.0 mg l^{-1}. Melack (1976a) reported a minimum concentration in Kisumu of 6.0

mg l^{-1}. Nyamu (1986) found oxygen concentration in Kisumu Bay to range from 4.8 to 7.9 mg l^{-1}. The concentrations recorded in the present study (6.8 to 11.8 mg l^{-1}) are similar to those previously reported.

5.1.3 UNDERWATER LIGHT PENETRATION

Underwater light penetration, which was estimated by Secchi disc visibility, was lower in the enclosed nearshore areas and increased in the more offshore stations of the Gulf. The lowest Secchi depth measured at Nyakach Bay (0.2 m) is not unusual. This is a river-influenced area where suspended solids, mainly silt and broken plant materials and other debris, are brought in by the inflowing River Nyando. The effect is the reduction of transparency and an increase in turbidity. The turbidity of Nyakach Bay was the highest recorded and was caused by the solids coming in through the river in addition to high algal biomass.

The Secchi depth at Kisumu Bay was lower than that of the other three sampling stations. This is an area with both river influence and organic pollution. River Kasat flowing into this bay is highly turbid and has a Secchi depth of less than 10 cm about 500 m upstream from the mouth. The very low Secchi depth recorded in Kisumu Bay in June, 1986 (0.3 m) was largely caused by the higher algal biomass as shown by the chlorophyll a values at that time (Fig. 16).

The relationship between light penetration of a water body and phytoplankton biomass (chlorophyll a) is an inverse one (Robarts, 1979). This relationship was found to be true for the Winam Gulf where a negative correlation between chlorophyll a and Secchi depth ($r = -0.695$) was recorded in the present study.

In the study by Melack (1976a) the Secchi depth in the Winam Gulf ranged between 0.75 and 1.5 m while Foxall et al. (1985) reported a mean value of 0.7 ± 0.3 m and a minimum value of 0.3 m at Kisumu Bay and near the mouth of River Nyando. In the present study, a similar minimum value (0.3 m) was recorded at Nyakach Bay. Although no measurement was taken at the mouth of River Nyando, the Secchi depth here would be expected to be lower than that of the Bay. While the Secchi depths measured by Foxall et al. (1985) are not markedly different from those of the present study, those of Melack (1976) showed a higher transparency of the water, which suggests a deterioration of the water quality over the years. Continuous monitoring of factors leading to this change of water quality is therefore of paramount importance in the Gulf.

Plotted on a logarithmic scale against depth, PAR showed a linear decrease with increasing depth (Fig. 12). Lower penetration was found to occur at stations with high turbidity caused either by high algal densities or suspended solids, or both, as was the case at Nyakach Bay (station 5). Here the PAR declined rapidly, attaining a value close to zero μ E (micro Einsteins) $cm^{-2}S^{-1}$ at 1.5 m. High algal densities are often associated with a reduction of PAR penetration, which explains the higher penetration at station 2, 3, and 4. The penetration of PAR through the water column is usually increased by reduced algal standing crop. This in turn usually results in increased photosynthesis (Robarts, 1979).

5.1.4 pH, CONDUCTIVITY AND ALKALINITY

The water pH remained fairly constant over the period of the present investigations with values ranging only between 7.5 to 9.0. There was, however, a marked trend of increased pH values during the rainy season. This is mainly due to the effect of dilution of the lake water by direct precipitation and runoff.

River inflow is usually of a lower pH than the lake water while rain water has a pH of about 7.0. During the rainy season, the effect of dilution outweighs the effect of CO_2 released by the biota which would lower the pH.

The relatively lower pH values encountered in enclosed bays are due to an influence of the respiratory activities of the biota. The relatively higher algal and zooplankton densities in such areas cause the release of more carbon dioxide into the water, thereby lowering the pH. Distribution of pH was nearly uniform throughout the water column. Differences between the surface and bottom values at any one time did not exceed 0.5 units. The pH of the Winam Gulf does not appear to change considerably over a long period of time. Graham (1929) and Worthington (1930) reported a pH value of 8.2 and 8.75 in December 1960 and May 1961, respectively. All these values are much similar to those reported in this study.

The diurnal changes of pH at Nyakach Bay show that the highest value at 1400 h corresponded with the time of highest oxygen concentration. This is the period of high photosynthetic activity when carbon dioxide fixation is occurring and oxygen is being evolved. After 1600 h pH fell continually until 2000 h when it rose slightly falling again at 2300 h. The decline in pH is caused by the release of carbon dioxide by the respiration of organisms during night time.

The change of electrical conductance of water in the Winam Gulf from 118 $\mu S\ cm^{-1}$ near Ndere Island (Station 3) to 1148 $\mu S\ cm^{-1}$ at Nyakach Bay (station 5) is an indication of changing water quality from the enclosed areas of the Gulf outward toward the outer Gulf. Foxall _et al_. (1985) found conductivity to decline along an East - West transect form Kisumu across the Winam Gulf to the main lake. This would suggest a progressive removal of ions by sedimentation and by assimilation by the organisms away from areas of river influence. The highest conductivity recorded by Foxall *et al*. (1985) was 151 µS cm^{-1} and the mean value for the Gulf was 140 ± 13 µS cm^{-1}. These values are very close to the highest recorded in the present study (148 µS cm^{-1}) and that of 145 µS cm^{-1} recorded by Talling & Talling (1965) in December 1961.

Conductivity values were generally higher during the dry season than during the wet season. This is seen from the rise in conductivity in July to August 1986 and again in November to January which were spells of lower rainfall. During the rainy season, although inflowing rivers and runoff may bring water of high conductivity, the effects of dilution by direct rainfall is likely to lower the conductivity of the lake water. Melack (1979a) reported conductivities as high as 170 - 179 µS cm^{-1} in the Winam Gulf. These appear rather high values as compared with those of the present study, which are close to those of Talling & Talling (1965).

The low conductivity of Lake Victoria can be attributed to high precipitation and high inputs of fresh water by the inflowing rivers. The much lower precipitation in some other lakes especially in the Rift Valley, the seasonality of the rivers that feed them, underground seepage and the high rates of evaporation cause high conductivities in the lake water through concentration of ions (Njuguna, 1982).

The high conductivity encountered at Nyakach Bay may not be unexpected. The River Nyando flowing into this bay brings dissolved ions from the rocks over which it flows together with nutrients form agricultural land, especially during the rainy season, which raises conductivity. The conductivity of the river at Ahero Bridge, a few kilometers from the river mouth was 183 μS cm $^{-1}$ on 15 May, 1986, showing that the river water has a higher conductivity than the lake water and is likely to have an influence when it enters the lake. This effect, however, is reduced by precipitation, sedimentation and assimilation.

Like conductivity, alkalinity showed little vertical variation. Relatively higher values were found at the inshore areas, Nyakach and Kisumu Bays, than the rest of the sampling stations. The lowest value was measured near Ndere Island (station 3) in February and May 1986, a period of relatively high rainfall, while the highest value was recorded in Nyakach Bay in December 1986, a period of relatively lower rainfall (see Fig. 5). The lower alkalinity during the wet season results from the effect of dilution of the lake water by direct precipitation. During the dry season, on the other hand, the process of evaporation causes both carbonates and bicarbonates to reach high concentrations which raise the alkalinity of the lake water. Talling and Talling (1965) reported an alkalinity value of 72 mg $CaCO_3 + HCO_3$ l^{-1} in the Winam Gulf. This compares well with the values recorded in this study (52 - 77 mg $CaCO_3$ + HCO_3 l^{-1}). The low alkalinity at station 3 is indicative of the decreasing alkalinity away from river - and urban - influenced areas of the Gulf.

5.2 CHLOROPHYLL A AND PHYTOPLANKTON VOLUMES

Chlorophyll a is found in all phytoplankton and is the primary photosynthetic pigment. Its determination remains the best method of estimating microalgal biomass in natural waters (Whitney & Darley, 1979). it has been used as a parameter for the measurement of algal standing crops in productivity studies of lakes and the sea (Moss, 1968).

The much higher chlorophyll a values at Nyakach Bay were due to high algal densities there which were sustained by increased nutrient inputs through the inflowing River Nyando. The shallowness of this bay also allows complete mixing by winds causing nutrients to be resuspended from the sediment (cf. Symoens et al. 1981). Such mixing was characterized by silt-laden brownish lake water.

The fact that the high chlorophyll a concentration here was caused by increased nutrient levels is shown by the direct relationship that exists between chlorophyll a and PO_4 - P (Table 3). High concentrations of chlorophyll a usually suggest considerable phytoplankton production dealt with later in this chapter.

Table 7. Chlorophyll a and productivity values of the Winam Gulf compared with those of other tropical African Lakes.

Lake	* Class	Type	Period	Chl. a ($\mu g\ l^{-1}$)	Productivity ($g\ O_2\ m^{-2} d^{-1}$)	Origin
Naivasha	I	Freshwater	1973 – 74	52.0	4 . 7	Melack (1979a)
Naivasha	I	Freshwater	1979	61.2	9 . 2	Njuguna (1982)
Oloidieni	II	Moderately saline	1973	84.0	8 . 1	Melack (1979a)
Sonachi	II	Moderately saline	1979	40.9	10 . 8	Njuguna (1982)
Victoria	I	Freshwater	1960 – 61	43.5	7 . 4	Talling (1965)
Simbi	III	Saline	1976	200	19 . 2	Melack (1979a)
Baringo	II	Moderately saline	1976 – 77	14.9	0 . 7	Kallqvist (1980)
Aranguadi	III	Saline	1966	325	16 . 4	Talling et al (1973)
George	I	Freshwater	1966 – 70	152	12 . 0	Ganf (1974b)
McIlwaine	I	Freshwater	1975 – 76	93.0	11 . 7	Robarts (1979)
Winam Gulf	I	Freshwater	1960 – 61	23.4		Talling (1966)
Winam Gulf	I	Freshwater	1974	17.0		Melack (1976)
Winam Gulf	I	Freshwater	1984	17.2	—	Foxall et al (1985)
Winam Gulf	I	Freshwater	1984	21.8	—	Nyamu (1986)
Winam Gulf	I	Freshwater	1986	**27.0**	10 . 4	Present study

* Classification of Talling & Talling (1965)

Two maxima of chlorophyll a concentration were observed in the Gulf. The higher maximum occurred in May - June 1986 and was caused by the Cyanophyte species, Microcystis aeruginosa Kutzing. which was in bloom. Its biomass reached a high value of 150 mg m^{-3} in Nyakach Bay in June, 1986 and was the highest biomass of a single species recorded. The second maximum in November 1986 to January 1987 was caused by the contribution of a mixture of different algal species, although Microcystis aeruginosa still dominated the phytoplankton biomass.

It is important to note that both phytoplankton volumes and chlorophyll a concentrations were higher during periods of increased rainfall and, indeed, both reached their peaks in May and June. The studies by Tolstoy (1977, 1979) in Lake Malaren, Sweden, have shown the existence of a strong relationship between chlorophyll a and phytoplankton volumes. Willen (1972) has further pointed out that normally chlorophyll a and phytoplankton densities correspond and any differences that may occur are due to varying chlorophyll a content of different algal groups.

Chlorophyll a and Secchi disc visibility show an inverse relationship (Fig. 12). This would be expected as chlorophyll a is a function of algal density which raises the turbidity of the water and hence lowers light penetration and transparency. The light absorbing capacity of chlorophyll a also lowers penetration of the PAR. This is best seen at Nyakach Bay where chlorophyll a values were highest and where both Secchi depth and FAR penetration were lowest. The reverse of this was true for station 3 (see Fig 12). The absorption of the FAR by photosynthetic pigments (mainly chlorophyll a) is an important limiting factor for photosynthetic productivity (Talling et al. 1973).

Depth profiles of chlorophyll a (Appendices 1 - 9) point to the fact that algal densities were highest just below the surface. This can be attribution to phytoplankton sinking or active regulation of depth by use of vacuoles, cilia or flagella to avoid ultraviolet light at the surface. Chlorophyll a peaks at the 0.5 to 1.0 m depth would indicate that this is the level in the water column where phytoplankton densities were highest. This pattern of chlorophyll a distribution with depth is in marked contrast to that of Lake George, Uganda. Here Ganf (1974a) observed an even distribution at dawn but at 1400 h the bottom concentration had risen to values more than double that near the surface.

Chlorophyll a concentrations measured in this study were far higher than those reported previously in the Winam Gulf. Talling reported a maximum value of 17 μg l^{-1}. Foxall et al. (1985) reported surface values ranging from 11.1 to 17.2 μg l^{-1}. However, in the present study, the highest mean value (36.5 μg l^{-1}) in the water column was twice as high as those mentioned here.

The algal standing crop of the Winam Gulf is higher than that of many other tropical lakes. Lake Naivasha, the second largest freshwater body in Kenya, for instance, has a mean chlorophyll a concentration of 21 $\mu g\ l^{-1}$ (Njuguna, 1982). However, Lake George has values as high as 400 $\mu g\ l^{-1}$ (Ganf, 1974b; 1975). The marked rise in phytoplankton density and chlorophyll a in the period between earlier studies and this study indicates that the water quality of the Winam Gulf is rapidly deteriorating.

5.3 NUTRIENTS

5.3.1 Phosphate - phosphorus

The concentration of phosphate - phosphorus was relatively higher at the inshore sampling stations than at the more offshore stations in the Winam Gulf. Kisumu Bay recorded relatively high phosphate concentrations with a mean value of 8.6 ± 6.8 $\mu g\ l^{-1}$ and ranked second to Nyakach Bay. Higher concentrations in the inshore areas than in offshore ones (see Fig. 29) are probably due to river influence and human activity especially in these two bays. In Nyakach Bay, the inflowing River Nyando flows through a rich agricultural area where farm fertilizers containing phosphates are in common use. During the rainy season, these find their way through surface runoff into the river and eventually into the bay. The concentration of phosphate - phosphorus in the Nyando water at its mouth was very high (46 $\mu g\ PO_4 - P\ l^{-1}$) in May 1986. Foxall et al. (1985)

reported a total phosphorus concentration of 43 μg l^{-1} at the Sondu River mouth a short distance south-west of Nyakach Bay. It has been shown that phosphorus emanates from rocks in increasing levels during the rainy season due to weathering (Golterman, 1973). This source would also cause an increase in phosphate levels especially in Nyakach Bay which is influenced by a river.

The high concentrations in Kisumu Bay are caused by human activity, mainly urbanization, with both treated and untreated effluents from Kisumu Municipality finding their way into this shallow Bay. Important among these are domestic wastes containing detergents and sewage. The study of Njuguna et al. (1985) showed that the phosphate concentration in Kisumu Bay was highest and values declined with increasing distance from Kisumu Town towards the outer Gulf.

Phosphate concentration in the Winam Gulf followed a pattern that corresponded with the rainfall pattern (Figs. 5 and 28).

Phosphate concentrations rose during the periods of increased rainfall. This was as a result of increased input through inflowing rivers, surface runoff and direct precipitation. This is well illustrated by the peak in May 1986 and 1987, months during which maximum rainfall was recorded in Kisumu (Fig. 5). In the Winam Gulf, river inflow, surface runoff and direct precipitation are the major sources of nutrient input. In the

Naivasha basin, rainfall was found to contribute substantial quantities of nutrients, 8 % N and 23 % P (Njuguna, 1982). Direct rainfall can provide a large part of the nutrient budget especially in the case of lakes with large surface areas such as the Winam Gulf. In Lake George 9 % N and 37 % P of the total inputs have been estimated from rainfall (Ganf & Viner, 1973). During the rainy season nutrient inputs emanate form bare agricultural lands, industrial air pollution, seeds, pollen dust, earth roads and bird droppings.

Concentrations of $PO_4 - P$ recorded in the present study indicate that there has been a marked increase between 1984 and 1986. Foxall <u>et al</u>. (1985) recorded 13 to 26 $\mu g \ PO_4 - P \ l^{-1}$, while an earlier study by Talling & Talling (1965) had reported a low value of 3 $\mu g \ l^{-1}$ in December 1960 in the Gulf. This markedly high rise in the phosphate level is an indication of increasing eutrophication of the Winam Gulf.

The depth profile of phosphate - phosphorus (Fig. 30) shows that concentrations were higher near the bottom than at the surface, although the difference was small. This observation was similar to that made by Talling & Talling (1965) in the main Lake Victoria. Here concentrations at 60 m were as high as 140 $\mu g \ l^{-1}$. The relatively higher concentrations of phosphate near the bottom may be caused by its capacity to absorb on silt (Golterman, 1969) and the subsequent settling of the silt.

5.3.2 Nitrate - Nitrogen

Nitrate concentrations ranged between 2.5 and 85 $\mu g\ l^{-1}$ during the period of the present study. This shows higher levels than the 15 - 28 $\mu g\ l^{-1}$ reported by Talling & Talling (1965). Hitherto, it has been held that nitrate concentrations in African lakes are usually below 30 $\mu g\ l^{-1}$ (Talling & Talling, 1965). The results of the present study, however, show that this value can be more than doubled in the Winam Gulf.

Mean concentration was highest at Nyakach Bay followed by station 4 off Dunga while the lowest mean concentration was recorded at Kisumu Bay. The high level at Nyakach Bay would be expected due to the effect of River Nyando entering the Gulf in this bay and bringing in nutrients from farmland especially during the wet season. The cause of the high concentrations encountered at station 4 may be more frequent upturning of the water column by high winds speed in this unsheltered shallow station, the effect of which is increased release of nitrate from the sediment. Concentration of nitrate - nitrogen at Kisumu Bay, though lower than the rest of the sampling stations, is considerably higher (23 ± 13 $\mu g\ l^{-1}$) than 15 ± 8 $\mu g\ l^{-1}$ reported by Njuguna _et al._ (1985) in the same area. This higher value in a period not exceeding two years indicates the rapid rate at which the water quality is changing due to eutrophication. This fact is more vividly clear when comparison is made between the results of the more recent studies and earlier ones such as the one of Talling (1966) where a value of 11 µg NO_3 - N l^{-1} was recorded. There appears, therefore, to be a progressive rise in nutrient levels in the Winam Gulf and it is imperative that regular monitoring be made and control measures be taken to curb this rise before it attains undesirable levels.

5.4 PRIMARY PRODUCTIVITY

In the Winam Gulf, rates of photosynthesis are greatly influenced by the various physical and chemical conditions. The transparency of the lake water decreases during periods of increased productivity. The relationship between light and productivity may vary depending on the phytoplankton assemblage present in the water and the prevailing illumination. The presence of Microcystis aeruginosa Kutzing., for instance, causes a self-shading effect near the surface which reduces productivity of the algae below it. This algal species is able to come to the surface by forming gas vacuoles (Dinsdale and Walsby, 1972). During blooms of Spirulina platensis (Norst) Geitl. self-shading was found to be the cause of low areal productivity in Ethiopian soda lakes (Talling et al. 1973). Increased productivity results in reduced transparency due to increased algal density which also lowers the water quality by imparting bad taste and odour.

Nutrient supply, mainly N and P have been stressed as the main factors controlling primary productivity in tropical African lakes (Talling & Talling, 1965; Peters & McIntyre, 1976; Melack, 1976a, 1979b; Gaudet & Muthuri, 1981; Melack et al. 1982; Njuguna, 1982). Primary productivity in the Winam Gulf is greatly influenced by availability of nutrients. Higher productivity was measured at those stations that recorded higher nutrient levels, notably, the nearshore areas influenced by river inflow or human activity. Mean monthly productivity was higher at Nyakach and Kisumu Bays than in the rest of the sampling stations. Nyakach Bay is influenced by River Nyando, which brings nutrients into the bay as described earlier, while Kisumu Bay receives nutrient inputs through the sewage effluents from the Kisumu Municipality through River Kasat and from Kisumu abattoir. Photosynthetic productivity declined in the stations away from Nyakach and Kisumu Bays with values being lowest at station 3 (Ndere Island) a station with no river influence. Nutrient concentrations, especially phosphate, followed a similar trend. The study of Njuguna et al. (1985) showed a decline in nutrient levels along an East-West transect from Kisumu Town toward the outer Gulf.

During the study period there was no month that could be described as having been a completely dry month but rather rainfall pulses varied from month to month.

The pattern of primary productivity in the Winam Gulf shows that rainfall has a marked influence on the primary productivity. Increased nutrient inputs through rain, runoff and river inflow are the major causes of increased productivity during the wetter seasons. The Gulf region has a high population of 2.1 million people (1979 census) and a mean density of 170 people per sq. km. It is a highly agricultural area with 0.75 million livestock population. During the rainy season, nutrients and organic wastes are washed into the rivers flowing into the Gulf which cause a rise in phytoplankton growth and photosynthetic rates. In Lake Naivasha, variation of productivity was correlated to changes in lake levels with increasing rainfall leading to increased photosynthetic rates (Njuguna 1982). A similar increase in phytoplankton productivity with increased rainfall was reported in a Nigerian fish pond (Imevbore et al. 1972). Mavuti & Litterick (1981) reported an increase in the numbers and biomass of zooplankton of Lake Naivasha following an incident of high water caused by increased rainfall.

That a rise in nutrient levels is a major factor influencing primary productivity can be deduced from the observation of higher productivity when phosphate levels were high. The importance of phosphate in this respect appears to be greater than that of nitrate. The presence of higher phosphate levels triggered higher productivity but this did not appear to be the case with nitrate. Phosphorus thus appears to be limiting phytoplankton productivity in the Winam Gulf. The regulation of photosynthetic productivity by phosphate is further illustrated by the high positive correlation existing between the two (r = 0.913, Table 3). This is in contrast to the low correlation between productivity and nitrate (r = 0.323). In tropical African lakes, P and N have been found to be the only nutrients that usually limit phytoplankton growth (Kalff, 1983; Symoens _et al_. 1981). In Lake George for instance, the water was shown to have a shortage of P and N with N being more important (Viner, 1973).

Results of the present study indicate that the primary productivity of the Winam Gulf is higher than has been reported hitherto. Talling (1965) reported a maximum productivity of 0.65 g O_2 m^{-3} h^{-1}. Later Melack (1979a) measured a close rate of 0.64 g O_2 m^{-3} h^{-1}. The highest value of productivity measured in the Winam gulf during this study was 1.2 g O_2 m^{-3} h^{-1} at Nyakach Bay (station 5) in January 1987, this being almost twice as high as previously reported values.

The highest annual mean (074 g O_2 m^{-3} h^{-1}) was recorded at Nyakach Bay and was higher than any earlier reported value. The Winam Gulf exhibits considerably high productivity compared with many other lakes in Kenya. The hourly productivity of Lake Naivasha, for instance, is 0.24 g O_2 $m^{-3}h^{-1}$ (Melack, 1979a) while the daily productivity is 9.2 g O_2 m^{-2} d^{-1} (Njuguna, 1982). This is a higher value than 4.7 g O_2 m^{-2} d^{-1} reported earlier by Melack (1979a), illustrating the capacity of tropical lakes to change their productivity markedly.

The highest daily photosynthetic rate measured in the Winam Gulf during the present study was 10.4 g O_2 m^{-2} d^{-1} in Nyakach Bay in November, 1987 a higher value than 7.4 g O_2 m^{-2} d^{-1} reported for Lake Victoria (Talling, 1966). These values are, however, lower than those of Lake George, where a net photosynthetic rate of 12 g O_2 m^{-2} d^{-1} has been reported (Ganf, 1974a). Table 6 gives the photosynthetic rates of several African lakes as compared with those of the Winam Gulf.

Productivity and chlorophyll a concentrations show a good relationship ($r = 0.873$, Table 4). Chlorophyll a is a measure of algal biomass and increases as productivity rises. This positive correlation between productivity and chlorophyll a has been shown in other lakes such as Lake Naivasha and Oloidien (Melack, 1979a; Njuguna, 1982).

Phytoplankton densities also correspond with photosynthetic productivity. The productivity peaks in June - August and November - February coincided with periods of increased algal densities in the Gulf. The increase in phytoplankton density resulting from a rise in nutrient levels consequently leads to increased productivity. Talling (1965) observed similar variations of productivity caused by variations in phytoplankton density in an offshore Lake Victoria station.

Depth profiles of productivity in the Winam Gulf show a familiar pattern of reduced rates near the surface than just below the surface. Within the water column, peaks were often found to exist at 0.5 m and sometimes at 1 m depths. The possible causes of suppressed productivity at the surface include photoinhibition of photosynthetic reactions and structures (Steeman-Nielsen, 1952; Ryther, 1956; Goldman et al. 1963), increased photorespiration (Harris & Lott, 1973) and sinking of phytoplankton (Talling, 1965). Below the depth of productivity peaks, values declined with increasing depth. This is caused by decreasing light intensity in the deeper layers of the water column due to absorption by the photosynthetic pigment, and self-shading by phytoplankton especially when blue-green algae are present (cf. Talling et al. 1973). Only one peak of productivity was found to exist in the water column during the study period which, as pointed out, lay at the 0.5 - 1.0 m depth. Melack (1976a) reported a similar occurrence in the Gulf.

Photosynthetic rates per unit chlorophyll a (specific photosynthetic activity) in the Winam Gulf exhibited a pattern of vertical distribution similar to that of primary productivity. Values were lower near the surface than at greater depths. Like photosynthetic rates, highest values were observed at 0.5 to 1 m depths and declined from here with increasing depth. This ratio of oxygen evolved during photosynthesis to chlorophyll a concentration may be influenced by a number of physical and chemical factors, among them light, temperature and nutrients. The availability of sufficient light and temperature in the water column would promote high specific activity. Increased light penetration due to low algal density and low levels of suspended solids thus enhances higher specific activity.

This explains the high specific activity at 0.5 m at station 2 on 6 March, 1987 as compared with 8 March, 1987 at station 1 (Kisumu Bay) at the same depth (Fig. 33). The latter station recorded higher algal biomass and turbidity than the former. The effect of light on specific photosynthetic activity is best appreciated by comparing values of Nyakach Bay at 0.5 m on 15 July 1987 with those of other stations. This station, which recorded the highest phytoplankton biomass exhibited a very low specific photosynthetic activity at 0.5 m depth.

Specific photosynthetic activities recorded for Lake Victoria ranged from 14 to 35 mg O_2 mg chl. $\underline{a}^{-1}$ h^{-1} in offshore subsurface waters and 12 mg O_2 mg chl. $\underline{a}^{-1}h^{-1}$ in nearshore areas (Talling, 1965). These values are much similar to those obtained in the present study (15-35 mg O_2 mg chl. $\underline{a}^{-1}h^{-1}$).

5.4.1 DAILY PHOTOSYNTHETIC RATES

Photosynthetic rates were higher at Nyakach Bay, station 5 than at the rest of the sampling stations (Table 7). As with volumetric photosynthetic rates, areal rates are governed by nutrient availability and algal density. Nyakach Bay with nutrient inputs through river inflow thus exhibits higher areal rates of photosynthesis than any other sampling station. The reduced rates from Nyakach Bay and Kisumu Bay towards Ndere Island (station 3) is an indication of reduced productivity in areas removed from river and urban influence.

5.5 SUMMARY

Primary productivity in the Winam Gulf is regulated by various physico-chemical factors, the principal ones among them being irradiance, temperature and nutrient availability. It exhibits a seasonality with values being higher in the rainy season than in the dry season. During the rainy season productivity rises as a result of increased nutrient input (notably phosphates and nitrates) through surface runoff, river effluents and direct precipitation.

Generally higher productivity values were recorded in the enclosed bays than in the more open offshore stations. Kisumu Bay (station 1) and Nyakach Bay (station 5) recorded higher productivity than the rest of the sampling stations. The former has urban influence while the latter has river influence. Kisumu Bay receives effluents from the Kisumu Municipality sewage lagoons through River Kasat besides a large amount of surface runoff, all of which raise nutrient levels in the bay. The intensive use of detergents in the car washing areas along the shore and effluents from the abattoir is an additional source of nutrients here. Nyakach Bay, on the other hand, receives the water of River Nyando which flows through a rich agricultural area from where farm fertilizers are washed down and eventually find their way into the Gulf, raising the nutrient levels.

Water quality improved with increasing distance outward away from the shallow inshore areas. This was shown by Secchi disc visibility which was lowest at Nyakach Bay and highest at Ndere Island. Visibility was lowest during the rainy season a time during which increased phytoplankton biomass and suspended solids raised the turbidity of the water. Levels of dissolved oxygen and pH also rose during the rainy season, the latter due to the effect of dilution by direct rainfall. Conductivity of the water increased during the dry season. A comparison between the results of the present study and those of previous works in the Gulf indicated that water quality has deteriorated over the last ten years as shown by higher values of chlorophyll a, lower Secchi disc visibility, higher nutrient levels and occurrence of algal blooms. The Winam gulf is thus a dynamic ecosystem whose changes call for close regular monitoring.

5.6 GENERAL RECOMMENDATIONS

Although apparent adverse effects of pollution are not being felt in the Winam Gulf, there is great need to monitor and control any factors that may lead to such adverse conditions. There is indication that the water quality of the Gulf has changed (deteriorated) during the last decade as shown by increased algal biomass, reduced transparency and the incidents of algal blooms, which indicate eutrophication of the Gulf.

To curtail further deterioration of water quality and a possible pollution stage where the biotic community is endangered, a change in the cultural practices and legislation of the Gulf have to be considered.

In Kisumu Bay, the Municipality should divert the effluents of the abattoir away from the lake. The large load of organic matter contained in these effluents causes a reduction of dissolved oxygen levels in the water. Similarly the industrial and domestic wastes that enter the Gulf through River Kasat ought to be diverted.

The level of treatment of any effluents from domestic and industrial sources should be raised to the national standards. With increasing industrialization within Kisumu Town and its immediate environs, the Kisumu Municipality and the Ministry of Water Development should intensify their policing activities by conducting frequent impromptu checks on the industries to ensure high standards of treatment of their effluents.

In Kisumu Town the Municipality should ensure that the numerous storm drains presently blocked are opened. Also the overflowing of septic tanks both in the homes and institutions together with burst sewage pipes left unattended for days should be checked. With the blockage of storm drains a lot of soil from untarmacked roads, paths and other uncovered parts of the town is washed down into Kisumu Bay during the rainy season. This reduces the transparency of the water. Also the oil from the open air garage areas is washed into the Bay. There is the need for the Municipality to ban any spillage of oil on open ground and to ensure that it is disposed of in other ways so as not to reach the lake. At the same time the servicing of motor boats and ships at the Kisumu Harbour should be done without allowing any spillage into the lake. Usually a film of oil covers the surface of water around the harbour. Car washing done at the lake shores should be banned as it adds oil and detergents into the lake.

Agricultural practices around the Winam Gulf affect the water quality largely. Nutrient levels rise during the rainy season as a result of farm fertilizers and livestock droppings being washed into the Gulf. A large amount of silt is also washed into the Gulf reducing water transparency.

There are numerous factors that cause deterioration of water quality of the Winam Gulf which, if they remain unchecked, will inevitably be a big threat to the biotic community in this ecosystem. These are mainly anthropogenic factors like urbanization and industrialization with domestic and industrial wastes entering the Gulf, together with agricultural practices which lead to eutrophication and siltation as described above. To avert this danger in the Winam Gulf, a concerted effort by all the authorities concerned is called for. For instance, the Kenya Marine and Fisheries Research Institute (K.M.F.R.I) and the Ministry of Water Development should act as watch-dogs to monitor industrial effluents that enter the Gulf and prosecute any industries whose level of effluent treatment falls short of the national standards. The contributions of the Lake Basin Development Authority and the Ministry of Agriculture ought to be those of educating farmers in the Gulf region on modern farming practices such as terracing on the slopes together with proper livestock management. The Kisumu Municipality ought to control the present multiplication of open air garages and devise methods of policing over these garages and other workshops to eliminate the wanton spillage of oil within the town. Planting grass on all open ground and constructing tarmac roads within the town will reduce the amount of silt entering Kisumu Bay and hence increase water transparency. It is only through this approach of involving various authorities within the Gulf region that the Gulf may be saved from advanced stages of pollution and eutrophication.

LITERATURE CITED

Alderg, S., Holmgren, S., Nauwerck, A. and Ramberg, L., 1971. Kompendium fur Undervisningen 1 Limnologie. Fytoplankton. Limnologiska Institution, Upsala. 133 p.

Arvola, L., 1981. Spectrophotometric determination of chlorophyll a and phaopigments in ethnol extractions. Ann. Bot. Fennici, 18: 221-227.

American Public Health Association, 1985. Standard methods for the Examination of water and Wastewater, including Bottom Sediments and Sludges. 16th edition. American Public Health Association, New York. 1268 p.

Bachmann, H., 1933. Phytoplankton von Victoria Nyanza und Kiogasee. Ber. Schweiz. Bot. ges. 42: 705-717.

Braarud, T., Gaardner, K.L. and Grontved, J., 1953. The phytoplankton of the North Sea and adjacent waters in May 1948. In: Sournia, A (ed.) 1978. Phytoplankton Manual. UNESCO Monograph. 337 p.

Burgis, M.J., Darlington, J.P.E., Dunn, I.G., Ganf, G.G., Gwahaba, J.J. and McGowan, L.M., 1973. The biomass and distribution of organisms in Lake George, Uganda. Proc. R. Soc. Lond. (B). 184: 271-298.

Desortova, B., 1981. Relationship between chlorophyll a concentration and phytoplankton biomass in several reservoirs in Czechoslovakia. Int. Revue ges. Hydrobiol. 66 (2): 153-169.

Dinsdale M.T. and Walsby, E.A., 1972. The interrelations of cell tugor pressure, gas vacuolation and buoyancy in a blue-green alga. J. Expt. Bot. 23: 561-570.

Edmondson, W.T., 1969. Eutrophication in North America. In: Eutrophication: causes, consequences, correctives. National Academy of Sciences, Washington D.C. 124-149.

Evans, J.H., 1961. Growth of Lake Victoria phytoplankton in enriched cultures. Nature 189: 417 p.

Faust, M.A. and Norris, H.K., 1982. Rapid in vivo spectrophotometric analysis of chlorophyll pigments in intact phytoplankton cultures. Br. Phycol. J. 17: 351-361.

Fish, G.R., 1957. A seiche movement and its effects on the hydroloy of Lake Victoria. Fish. Publ. Lond. 10: 1-68.

Foxall, C.D., Litterick, M.R., and Njuguna S.G., 1985. A preliminary study of water quality of Lake Victoria, Kenya. In: Chan, M.W.H., Hoare, F.R., Law, R.J.S. and Reed, S.B. (eds.) Pollution in the urban environment "POLMET" 85. Elsevier Applied Science Publishers, Lond. & N.Y. Environmental protection Agency, Hong Kong. 615-620.

Ganf, G.G., 1974a. Diurnal mixing and the vertical distribution of phytoplankton in a shallow equatorial lake (Lake George, Uganda). J. Ecol. 62 (2): 641-659.

Ganf, G.G., 1974b. Phytoplankton biomass and distribution in a shallow eutrophic lake (Lake George, Uganda). Ocologia 16: 9-29.

Ganf, G.G., 1975. Photosynthetic production and irradiance-photosynthesis relationships of phytoplankton from an equatorial lake (Lake George, Uganda). Oecologia 18: 165-183.

Ganf, G.G., and Horne, A.J., 1973. Diurnal stratification, photosynthesis and nitrogen fixation in a shallow equatorial lake (Lake George, Uganda). Freshwat. Biol. 5 : 13 - 39.

Ganf, G.G., and Viner, A.B., 1973. Ecological stability in a shallow equatorial lake (Lake George, Uganda). Proc. R. Soc. B. 184: 321-346.

Gaudet, J.J., and Muthuri, F.M., 1981. Nutrient relationships in shallow water in an African Lake, Lake Naivasha. Oecologia (Berl.) 49: 109-118.

Goldman, C.R., Mason, D.T. and Wood, B.T.B., 1963. Light injury and inhibition in antarctic freshwater phtoplankton. Limnol. Oceanogr. 8: 313-322.

Golterman, H.L., (ed.) 1969. Methods for physical and chemical analysis of fresh waters, 2nd Edition. Blackwell Scientific Publication, Oxford. 215 p.

Golterman, H.L., 1973. Natural phosphate sources in relation to phosphate budgets: a contribution to the understanding of eutrophication. Water Research, 7: 3-17.

Graham, M., 1929. The Victoria Nyanza and its Fisheries. In: Talling, J.F., 1966. The annual cycle of stratification and phytoplankton growth in Lake Victoria (East Africa). Int. Revue. ges. Hydrobiol. 51: 545-621.

Hammer, U.T., Walter, K.F. and Williams, W.D., 1973. Delivation of daily phytoplankton production estimates from short-term experiments in some shallow eutrophic Australian saline lakes. Aust. J. Mar. Fresh. Res. 4: 259-266.

Harris, G.P. and Lott, J.N.A., 1973. Light intensity and photosynthetic rates in phytoplankton. J. Fish. Res. Board Can. 30: 1771-1778.

Holm-Hansen, O. and Reinmann B., 1978. Chlorophyll a determination : improvements in methodology. Oikos 30: 438-447.

Imevbore, A.M.A., Moszes, G. and Boszvormenyi, Z., 1972. The primary productivity of a fish-pond at Ile-Ife, Nigeria. Proceedings of the IBP-UNESCO Symposium on productivity problems of freshwaters. (Eds. Z. Kajak and A. Hillbricht-Ilkowska). 715-723.

Jones, I.R., 1977. A comparison of acetone and methanol as solvents for estimating the chlorophyll _a_ concentrations in phytoplankton. _Ann. Bot. Fennici_ _14_: 65-69.

Kalff, J., 1983. Phosphorus limitation in some tropical African lakes. _Hydrobiol._ _100_: 101-112.

Kallqvist, T., 1980. _Primary production and phytoplankton in Lakes Baringo and Naivasha, Kenya._ Norwegian Institute for Water Research, Blindern, Oslo.

Kendall, R.L., 1979. An ecological history of the Lake Victoria Basin. _Eco. Monogr._ _39_: 121-176.

Kutkuhn, J.H., 1958. Notes on the precision of numerical and volumetric plankton estimates from small-sample concentrates. _Limnol. Oceanogr._ _3_ (1): 69-83.

Littleford, R.A., Newcombe, C.L. and Shepherd, B.B., 1940. An Experimental study of certain quantitative plankton methods. _Ecology,_ _21_(3): 309-322.

Marker, A.F.H., Nusch, E.A., Rai, H. and Reinmann, B., 1980. The measurement of photosynthetic pigments in freshwaters and standardization of methods: conclusions and recommendations. Arch. Hydrobiol. Beih. 14: 91-106.

Mavuti, K.M., and Litterick, M.R., 1981. Species composition and distribution of zooplankton in a tropical lake, Lake Naivasha, Kenya. Arch. Hydrobiol. 93: 52-58.

McAlice, B.J., 1971. Phytoplankton sampling with the Sedgwick-Rafter cell. Limnol. Oceanorgr. 16 (1): 19-28.

McGowan, J.A., 1971. Oceanic biogeography of the Pacific. In: B.M., Funnel and W.R., Riedel (eds.). The Micropaleontology of oceans. In: Sournia A., (ed.). 1978. Phytoplankton Manual. UNESCO Monograph. 337 p.

Melack, J.M., 1676a. Linmology and dymanics of phytoplankton in equatorial african lakes. Ph. D. Thesis, Duke University, Durham, NC. 453 p.

Melack, J.M., 1976b. Primary production and fish yields in tropical lakes. Transactions of the American Fisheries society. 105: 575-580.

Melack, J.M., 1979a. Photosynthetic rates in four African freshswaters. Freshwat. Biol. 9: 555-571.

Melack, J.M., 1979b. Temporal variability of phytoplankton in tropical lakes. Oecologia (Berl.) 44: 1-7.

Melack, J.M., and Kilham, P., 1974. Photosynthet rates of phytoplankton in East Africa alkaline, Saline lakes. Limnol. Oceanogr. 19: 743-755.

Melack, J.M., Kilham, P. and Fisher, T.R., 1982. Responses of phytoplankton to experimental fertilization with ammonia in an African soda lake. Oecologia 52: 312-326.

Moss, B., 1968. Studies on the degradation of chlorophyll a and carotenoids in freshwaters. New Phytol. 67: 49-59.

Nauwerck, A., 1963. Die Beziehungen Zwischen Zooplankton und Phytoplankton in See Erken. Symb. Bot. Upsal. 17 (5): 1-163.

Newell, B.S., 1960. The hydrology of Lake Victoria. Hydorbiol. 15: 363-383.

Njuguna, S.G., 1982. Nutrient-productivity relationships in tropical Naivasha Basin lakes, Kenya. Ph. D. Thesis, University of Nairobi. 300 p.

Njuguna, S.G., Foxall, C.D. and Litterick, M., 1985. Nutrients and phytoplankton of Lake Victoria (Kenya). Conference on the ecological status of Lake Victoria. Kakamega, March, 1985. 28 p.

Nyamu, A.M., 1986. An assesement of water quality in the Kisumu Bay area of the Winam Gulf, Lake Victoria, Kenya. M. Sc. Thesis, University of Nairobi. 138 p.

Ogalo, L., 1981. The trend of rainfall in East Africa. Kenya J. Sc. Tech. (A) 2: 83-90.

Paasche, E., 1960. On the relationships between primary production and standing stock of phytoplankton. J. Cons. Int. Explor. Mer. 26: 33-48.

Parsons, T.R. and Strickland, J.D.H., 1963. Discussions of spectrophotometric determination of marine plants pigments, with revised equations for ascertaining chlorophylls and carotenoids. J. Mar. Res. 21: 151-163.

Peters, R.H. and McIntyre, S., 1976. Orthophosphate turnover in East African lakes. Oecologia (Berl.) 25: 213-319.

Pieterse, A.J.H. and Toerien, D.F., 1978. The phosphorus-chlorophyll relationship in Roodeplaat Dam. Water SA 4 (3): 105-112.

Platt, T., 1971. The annual production by phytoplankton in St. Margaret's Bay, Nova Scotia. J. Cons. Int. Explor. Mer. 33: 324-333.

Robarts, D.R., 1979. Underwater light penetration, chlorophyll a and primary production in a tropical African lake (Lake McIlwaine, Rhodesia). Arch. Hydrobiol. 86: 423-444.

Ross, R., 1955. The algae of the East African great lakes. Proceedings of the International Association of Theoretical and Applied Limnology. XIII: 320-326.

Ryther, J.H., 1956. Photosynthesis in the ocean as a function of light intensity. Limnol. Oceanogr. 1: 61-70.

Sournia, A., 1978. Phytoplankton Manual. UNESCO Monograph. 337 p.

Smayda, T.J., 1958. Biogeographical studies of marine phytoplankton. Oikos 9 (2): 158-191.

Smayda, T.J., 1965. A quantitative analysis.......II. On the relationship between C14 assimilation and the diatom standing crop. In: Sournia, A., (ed.) 1978. Phytoplankton Manual. UNESCO Monograph. 337 p.

Steeman-Nielsen, E., 1952. On the detrimental effects of high light intensities on the photosynthetic mechanisms. Physiol. 15: 161-171.

Symoens, J.J., Burgis, M. and Guadet, J.J., (eds.) 1981. The ecology and utilization of African inland waters. UNEP Reports and Proceedings Series 1, Nairobi. 191 p.

Talling, J.F., 1957. Some observations on the stratification of Lake Victoria. Limnol. Oceanogr. 11 (3): 312-321.

Talling, J.F., 1965. The photosynthetic activity of plytoplankton in East African lakes. Int. Revnue ges. Hydrobiol. 50: 1-32.

Talling J.F., 1966. The annual cycle of stratification and phytoplankton growth in Lake Victoria (East Africa). Int. Rev. ges. Hydrobiol. 51: 545-621.

Talling, J.F. and Driver, D., 1963. Some problems in the estimation of chlorophyll a in phytoplankton. Proc. conference of primary productivity measurements, marine and freshwater, Hawii. 1961. U.S. Atomic Energy Comm. TID-7633: 142-146.

Talling, J.F. and Talling I.B., 1965. The chemical composition of African lake waters. Int. Rev. ges. Hydrobiol.. 50: 421-463.

Talling, J.F., wood, R.B., Prosee, M.V. and Baxter, R.M., 1973. The upper limit of photosynthetic productivity by phytoplankton: evidence from Ethiopian soda lakes. Freshwat. Biol. 3: 53-76.

Tolstoy, A., 1977. Chlorophyll a as a measure of phytoplankton biomass. Acta. Univ. Upsal. 416: 1-30.

Tolstoy, A., 1979. Chlorophyll a in relation to phytoplankton volumes in some Swedish lakes. Arch.Hydrobiol. 85 2: 133-151.

Viner, A.B., 1973. Responses of a mixed phytoplankton population to nutrient enrichments of ammonia and phosphate and some associated ecological implications. Proc. R. Soc. Lond. (B) 183: 351-370.

Vollenweider, R.A., (ed.) 1974. A manual on methods for measuring primary production in aquatic environments. IBP Handbook No. 12, Second Edition. Blackwell Sc. Pub., Oxford, Lond., Edinburgh, Melbourne. 225 p.

Vollenweider, R.A. and Nauwerck, A.,1961. Some observations on the C14 method for measuring primary production. Verh. Int. Ver. Limnol. 14: 134-139.

Wetzel, R.G. and Likens, G.E., 1979. Limnological Analysis. W.B. Saunders Company. Philadelphia, London, Toronto. 357 p.

Whitehouse, B. and Hunter, C.S., 1902. Victoria Nyanza. In: Melack, J.M., 1979a. Photosynthetic rates in four tropical African freshwaters. Freshwat. Biol. 9: 555-571.

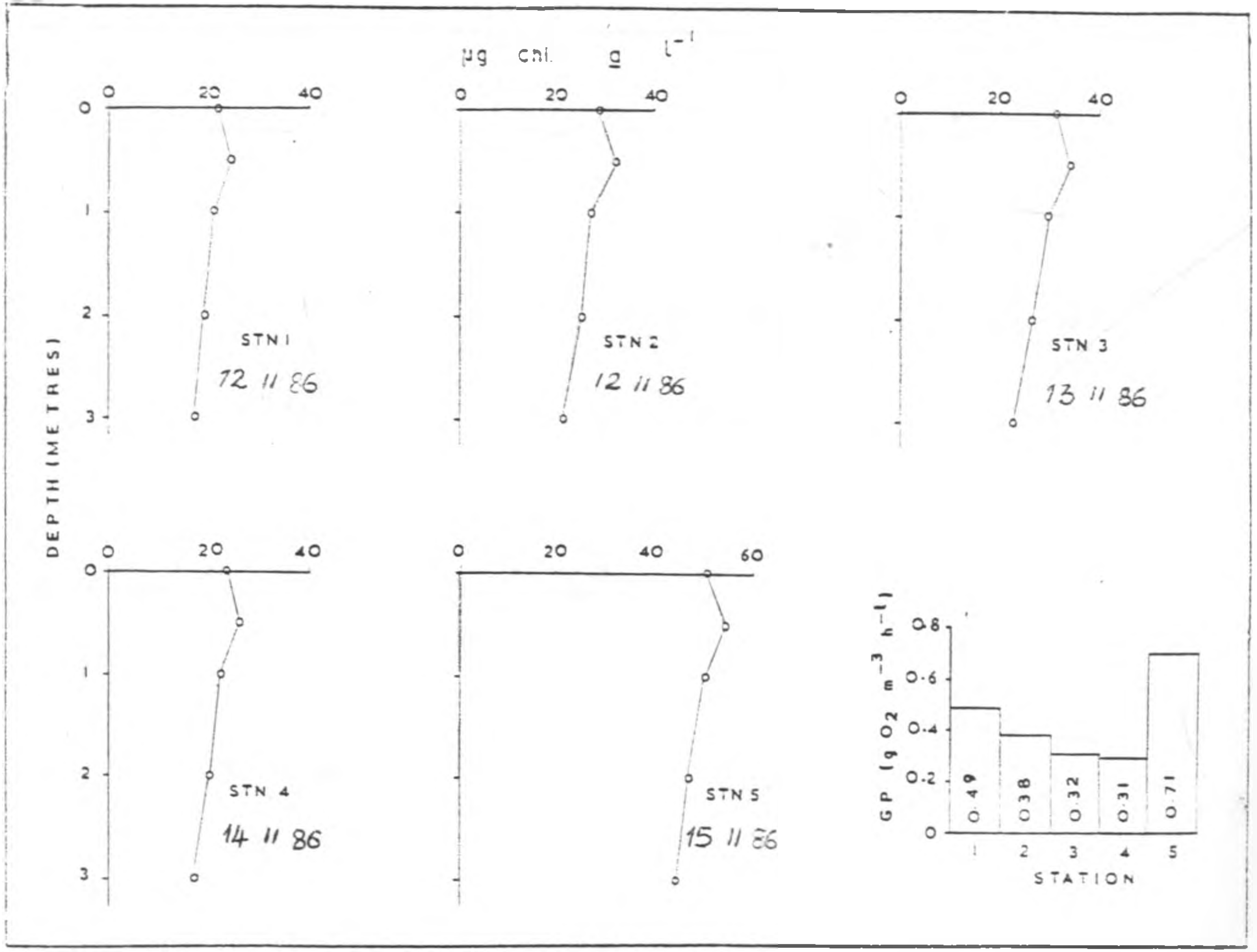
Whitney, D.E. and Darley, W.M., 1979. A method for determination of chlorophyll a in samples containing degradation products. Limnol. Oceanogr. 24 (1): 183-186.

Willen, T., 1972. The gradual destruction of Sweden's Lakes. Ambio. 1: 6-14.

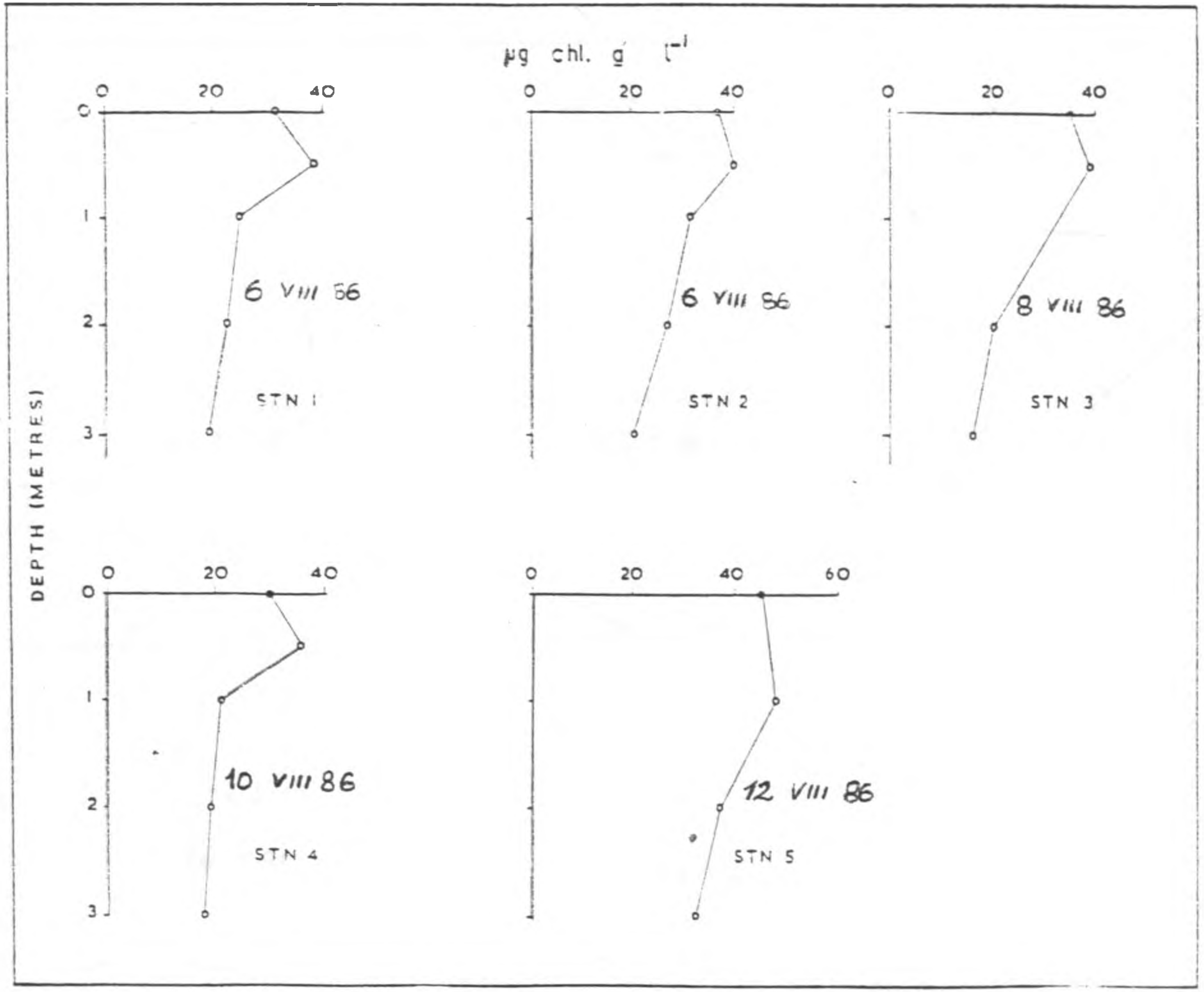
Worthington, E.B., 1930. Observation on the temperature, hydrogen ion concentration and other physical conditions of the Victoria and Albert Nyanzas. Int. Revue ges. Hydrobiol. 24: 328-357.

Zeitzschel, B., 1978. Why study phytoplankton? In: Sournia, A., (ed.). Phytoplankton Manual. UNESCO Monograph. 337 p.

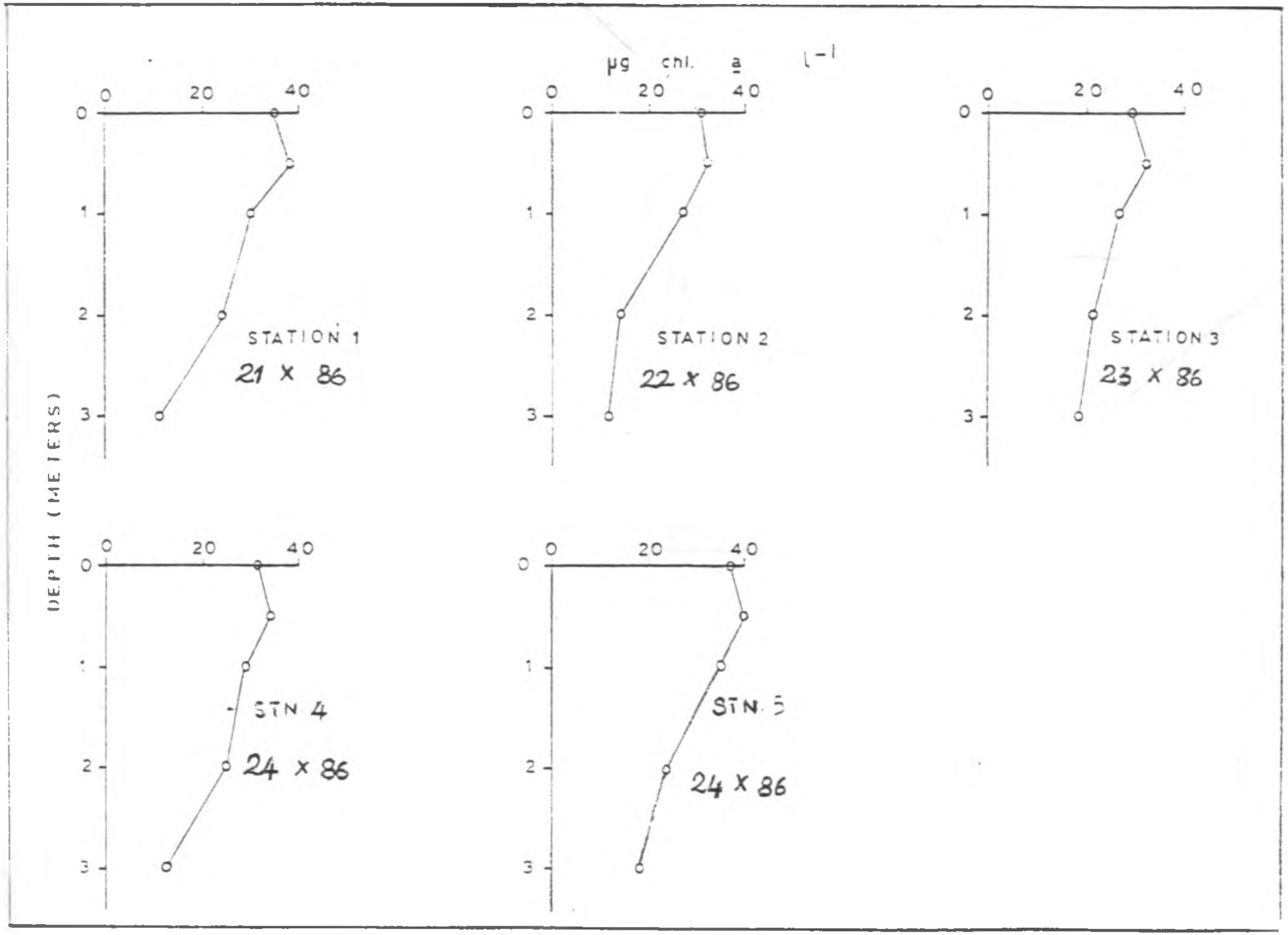
Appendices 1 - 9. Vertical distribution of chlorophyll a in the Winam Gulf during various months. (Inset in App. 1 shows productivity values at stations 1 to 5 in February, 1986).


μg chl. a l^{-1}
DEPTH (METRES)
0
20
40
60
0
1
2
3
STN 1
72 11 86
STN 2
12 11 86
STN 3
13 11 86
STN 4
14 11 86
STN 5
15 11 86
GP (g O$_2$ m^{-3} h^{-1})
0.8
0.6
0.4
0.2
0
0.49
0.38
0.32
0.31
0.71
1
2
3
4
5
STATION

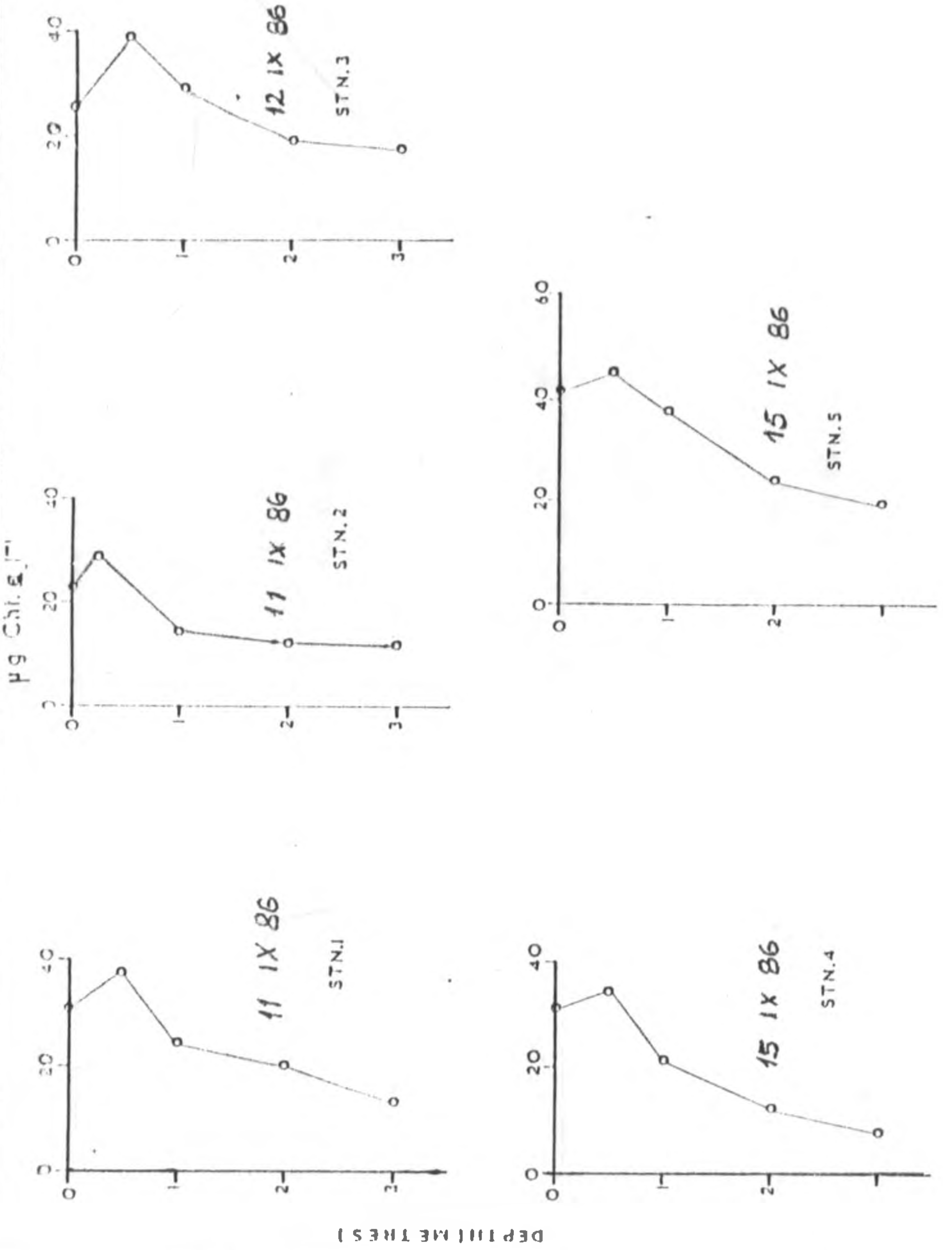
APP. I


µg chl. g l⁻¹
DEPTH (METRES)
0
20
40
60
0
1
2
3
6 VIII 86
STN 1
6 VIII 86
STN 2
8 VIII 86
STN 3
10 VIII 86
STN 4
12 VIII 86
STN 5

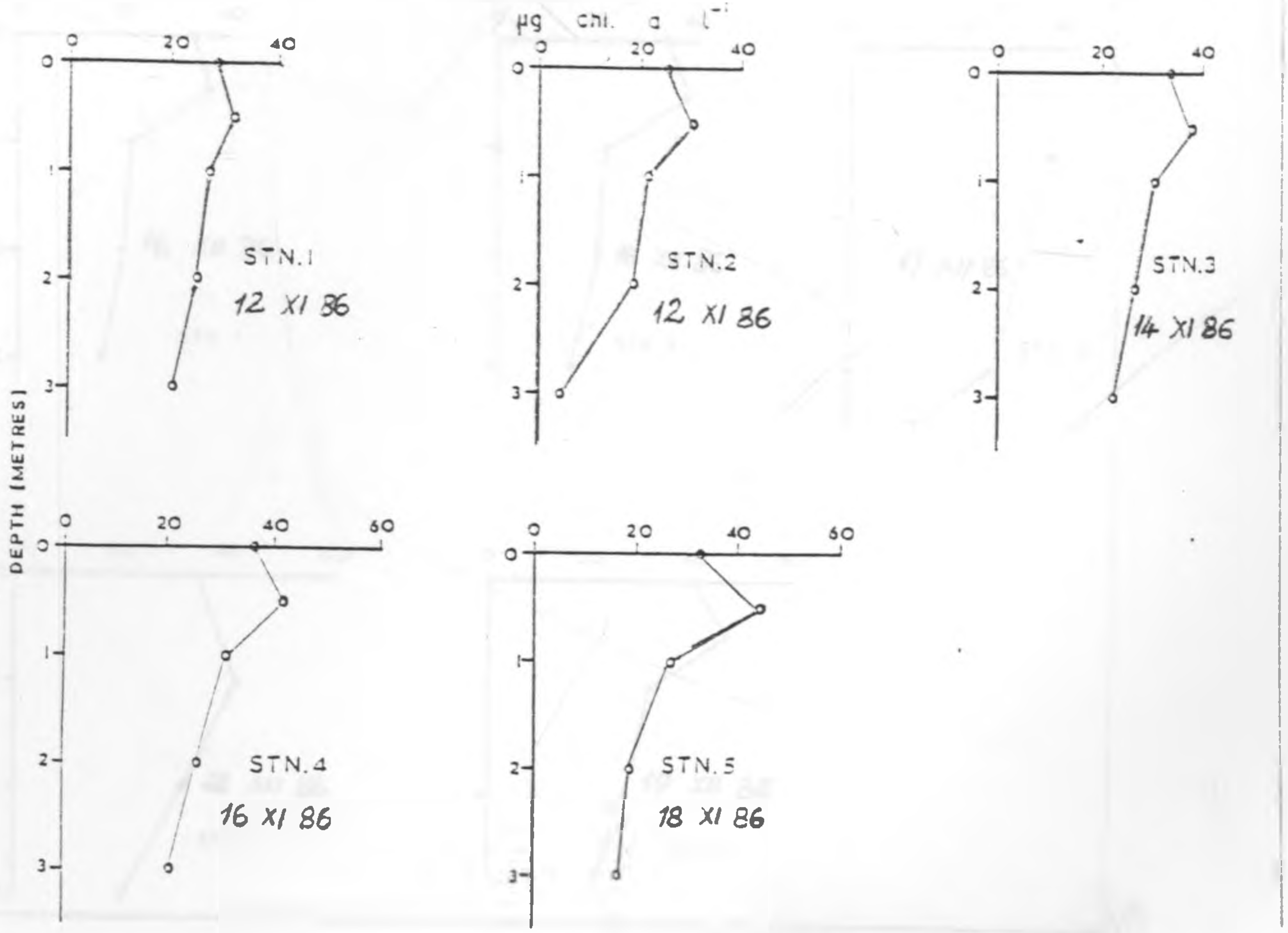
APP. 2

µg chl. a l⁻¹
DEPTH (METERS)
0
20
40
0
1
2
3
STATION 1
21 x 86
STATION 2
22 x 86
STATION 3
23 x 86
STN 4
24 x 86
STN 5
24 x 86

APP. 3

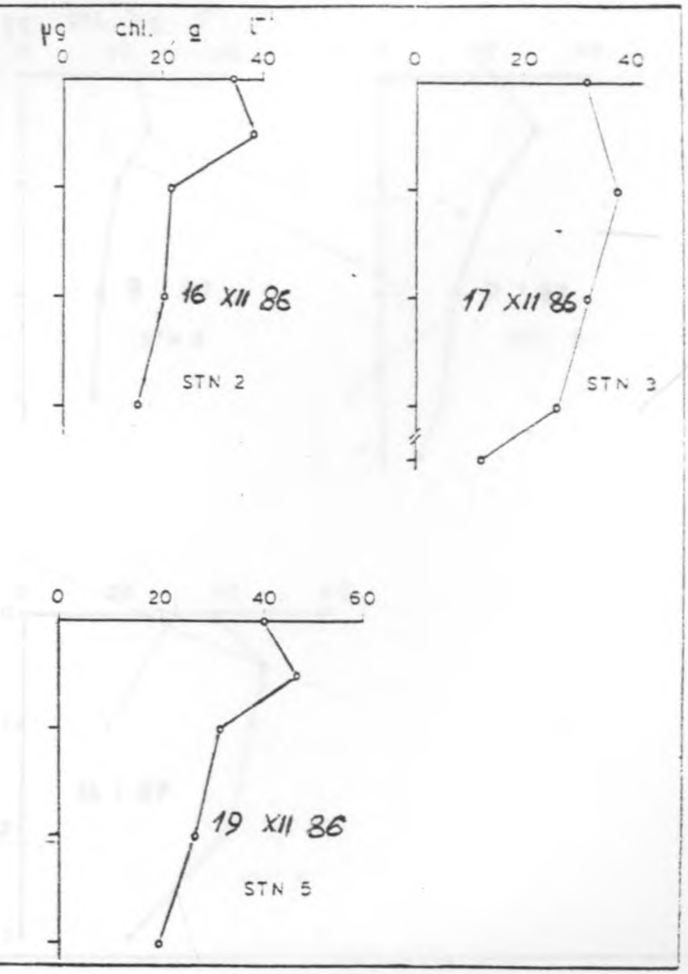

µg Chl.a l⁻¹
DEPTH(METRES)
11 IX 86
STN.1
11 IX 86
STN.2
12 IX 86
STN.3
15 IX 86
STN.4
15 IX 86
STN.5
0
20
40
60
0
1
2
3

APP. 4

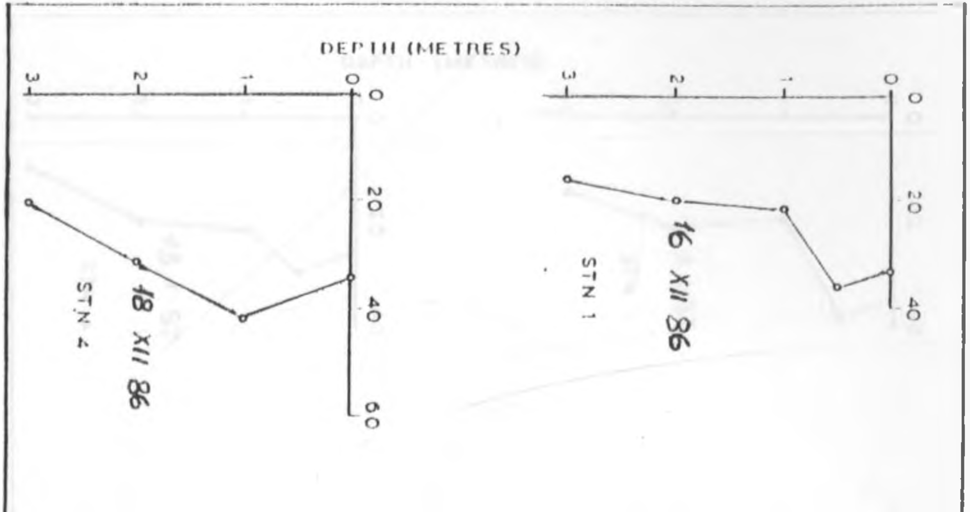


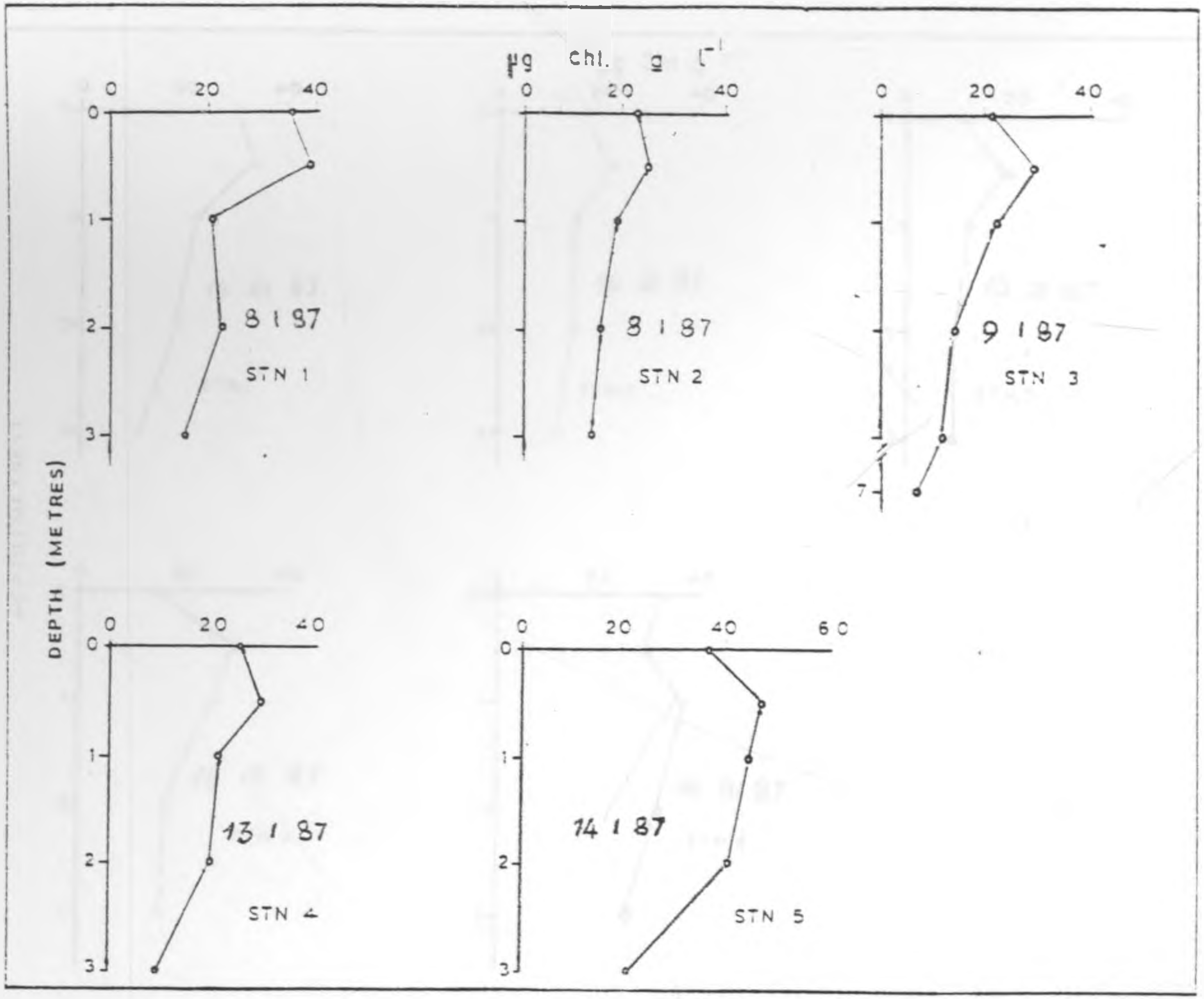
µg chl. a l⁻¹
DEPTH (METRES)
0
20
40
60
0
1
2
3
STN.1
12 XI 86
STN.2
12 XI 86
STN.3
14 XI 86
STN.4
16 XI 86
STN.5
18 XI 86

APP. 5

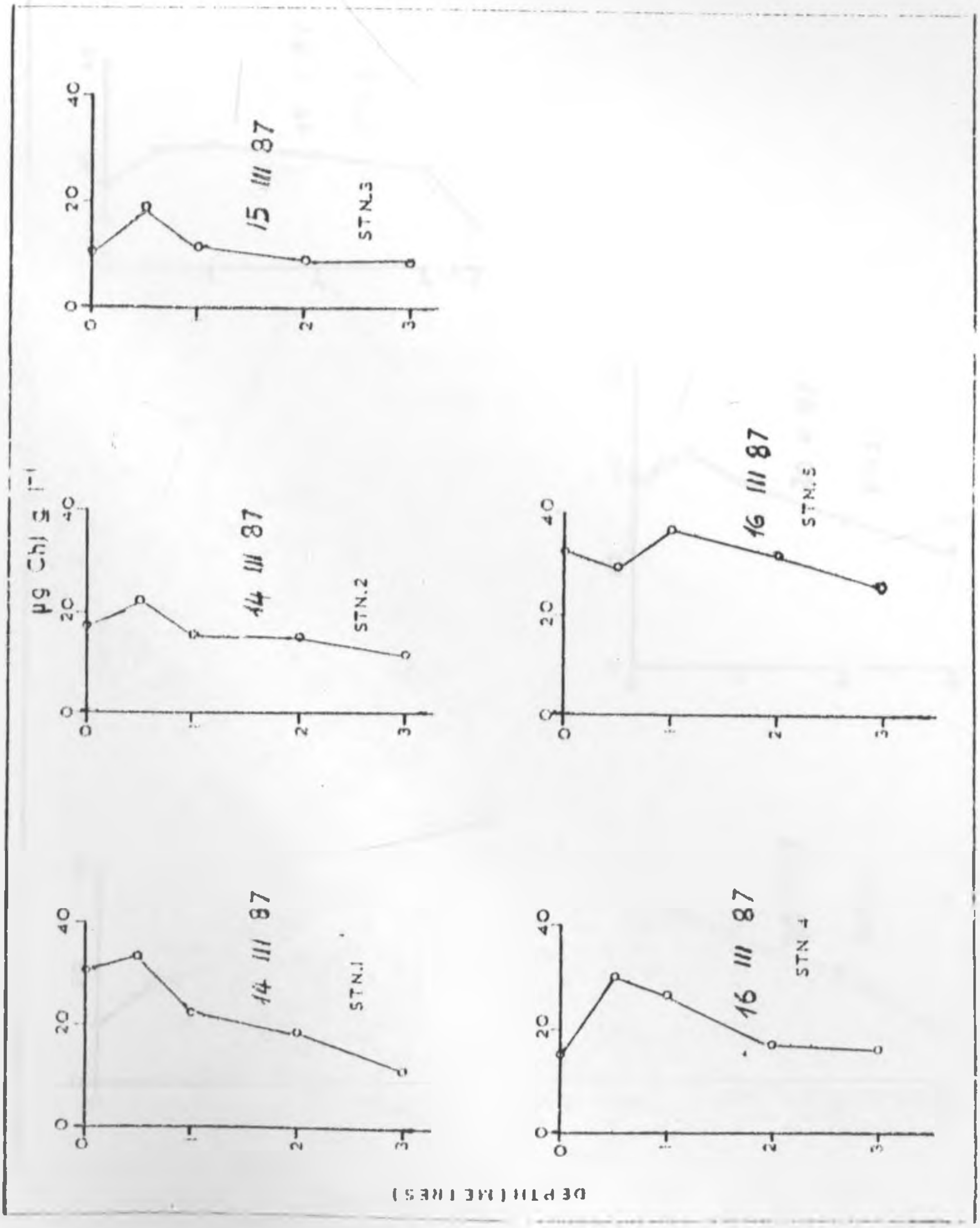

µg chl. a l⁻¹
0
20
40
16 XII 86
STN 2
0
20
40
17 XII 86
STN 3
0
20
40
60
19 XII 86
STN 5

APP. 6

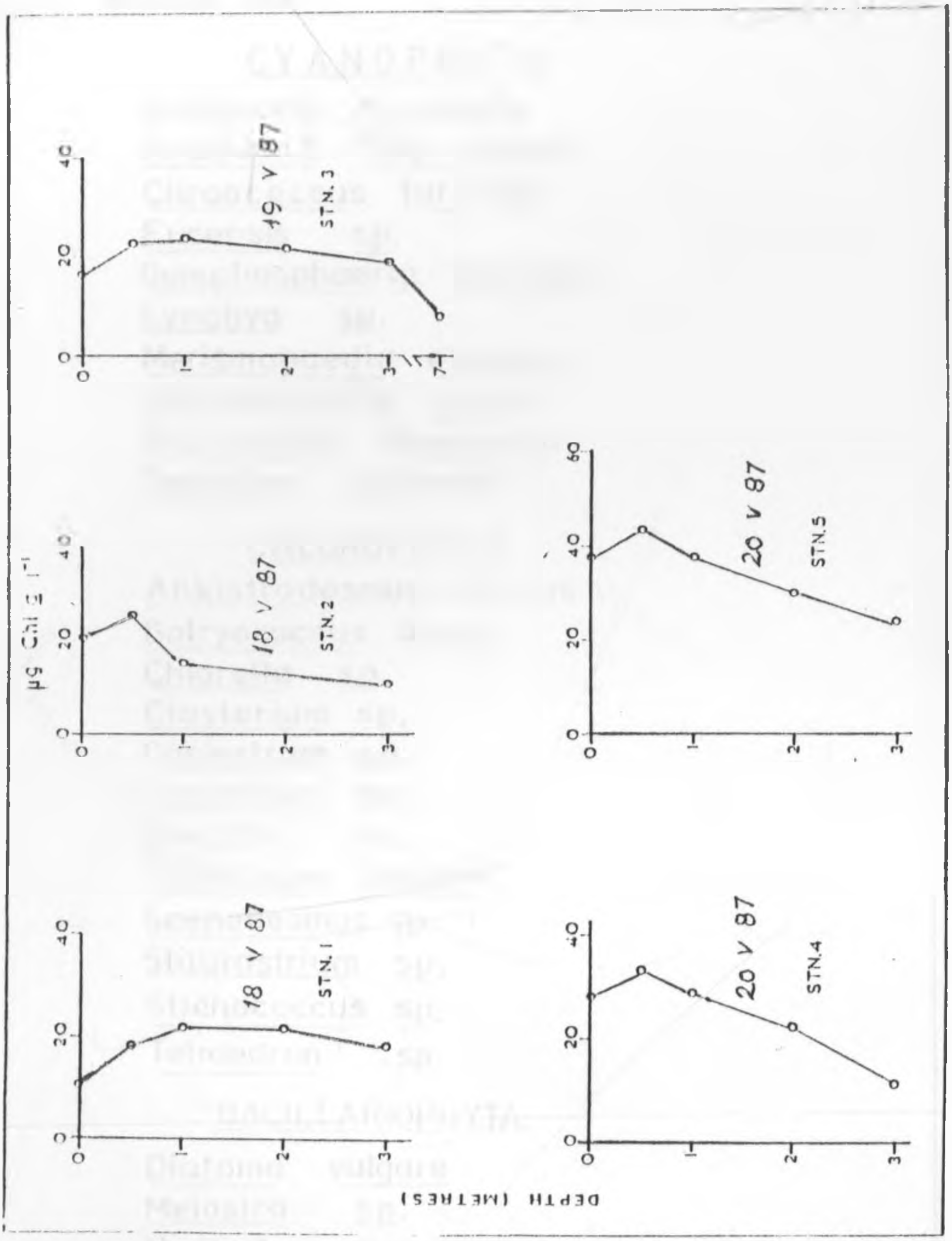



µg chl. a l⁻¹
DEPTH (METRES)
0
20
40
60
0
1
2
3
7
8 I 87
STN 1
8 I 87
STN 2
9 I 87
STN 3
13 I 87
STN 4
14 I 87
STN 5

APP. 7


µg Chl a l⁻¹
DEPTH (METRES)
14 III 87
STN.1
14 III 87
STN.2
15 III 87
STN.3
16 III 87
STN.4
16 III 87
STN.5
0
20
40
0
1
2
3

APP. 8


µg Chl a l⁻¹
DEPTH (METRES)
18 V 87
STN.1
18 V 87
STN.2
19 V 87
STN.3
20 V 87
STN.4
20 V 87
STN.5
0
20
40
60
0
1
2
3
7

APP. 9

APP. 10. List of common phytoplankton species in the Winam Gulf.

CYANOPHYTA

Anabaena circinalis
Anabaena flos-aquae
Chroococcus turgidus
Eucapsis sp.
Gomphosphaeria aponina
Lyngbya sp.
Merismopaedia elegans
Merismopaedia glauca
Microcystis aeruginosa
Spirulina platensis

CHLOROPHYTA

Ankistrodesmus falcatus
Botryococcus brauni
Chlorella sp.
Closterium sp.
Coelostrum sp.
Cosmorium sp.
Oocystis sp.
Pediastrium simplex
Scenedesmus sp.
Staurastrium sp.
Stichococcus sp.
Tetraedron sp.

BACILLARIOPHYTA

Diatoma vulgare
Melosira sp.
Navicula sp.
Nitzschia sp.
Surirella sp.
Synedra sp.

EUGLENOPHYTA

Euglena sp.
Phacus sp.