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I

SEASONAL CHANGES IN THE PHYTOPLANKTON POPULATION IN THE COASTAL WATERS OF GHANA.

A thesis submitted in July, 1976

By

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II

I the undersigned, Emelia Roseline Anang, the author of this thesis do hereby declare that no part or parts of this thesis has been submitted for a degree elsewhere.

Signed: Emelia Roseline Anang.

Subject | Page

LIST OF FIGURES

Figure

LIST OF TABLES

A B S T R A C T

Seasonal changes in the phytoplankton at four depths at station A1, off Tema, Ghana were investigated between September 1973 and November 1974. The physico-chemical factors show that there are two marine seasons, the season of major upwelling (July-October) characterised by low water temperatures (25°C), high salinity (35°/00) and high nutrient levels, and a non-upwelling period (November-June) when water temperatures are higher and salinity and nutrients are lower. The latter marine season is broken by a small unpredictable upwelling (December-January). Phytoplankton cell counts and chlorophyll a concentrations are high during the major upwelling period and low during the non upwelling period. Dinoflagellates form the main components of the phytoplankton population during the non-upwelling period and the diatoms form the dominant components at other times. Primary productivity rates are high (>1,000 mg C/m^2/day) during the upwelling period and low (<700mg C/m^2/day) outside the upwelling period. There is a close relationship between the physico-chemical factors and the phytoplankton population. Grazing may also account for some of the sudden drops in cell numbers. Productivity, cell counts and chlorophyll a concentration are usually highest at 5m and below except when the ciliate Mesodinium rubrum was present. This positively photo-tactic ciliate containing algae as incomplete endosymbionts was in greatest cell numbers at the surface when sampled.

I. INTRODUCTION

Seasonal changes in the composition and abundance of phytoplankton in the temperate - parts of the North Atlantic are well documented (see Riley 1941, 1946, Patten et al. 1963, Steemann Nielsen 1964, Robinson 1970, Williams and Robinson 1973, among others). However until recently little was known of the phytoplankton found along the West African Coast. Much of our knowledge of the West African phytoplankton is provided by the recent series of investigations by Reyssac (1966a, 1966b, 1966c, 1967, 1969, 1970, 1973b, 1974, 1975), Reyssac and Prive (1965), Reyssac & Roux (1972) and Dandonneau. (1970, 1971, 1972a, 1972b) Many of these West African publications are of short term studies but some of those undertaken in the Gulf of Guinea provide detailed information on phytoplankton cycles over one or more seasons.

A number of publications have appeared in the past two decades which include records of marine phytoplankton off the North-West African coast. For instance changes in the local phytoplankton off the coast of Mauritania have been reported by a number of workers such as Herbland et al. (1973), Lloyd (1971), Marche - Marchad (1956) and Reyssac (1973b, 1974, 1975). Bessonov & Fedosov (1965) and Nellen (1969) have carried out primary productivity studies off the coast of Senegal where the colder waters (< 24°C) of the Canary current

meets the warmer Guinea water. They reported large production rates varying from 490 to 5,200 mg C/ m^2/ day depending on the season. Bainbridge (1960) worked on the seasonal changes in the phytoplankton in the brackish waters of the estuary of the Sierra Leone River. Apart from these there is a brief mention of phytoplankton organisms found further south along the coast such as in Liberia, Guinea, and Nigeria (Nellen 1969) and in Angola (Reyssac 1972, 1973a).

The most comprehensive of the West African phytoplankton studies have been those of Reyssac (1966a, 1966b, 1967, 1969, 1970) and Dandonneau (1970, 1971, 1972a, 1972b) off the Ivory Coast in the Gulf of Guinea. They have shown that there are three main phases in phytoplankton development, low numbers of phytoplankton organism from February to June, high number from July to the beginning of November and finally another small increase between January and February. The highest values for phytoplankton, productivity (985 - 1,166 mg C /m^2/day) were recorded between July and October whilst low productivity values (139 - 386 mg C /m^2/day) were found for the rest of the year. Similarly there were seasonal changes in the composition of the phytoplankton with diatoms forming the dominant components during the local upwelling (July to November) when water temperatures were low whilst dinoflagellates were the dominant components at other

times when the temperatures were high (7 25 ^{o}C). Many species form the components of these two groups and Reyssac (1970) lists 100 species of diatoms and 158 species of dinoflagellates.

Unlike the Ivory Coast the phytoplankton off the Ghanaian coast have not been studied continuously. Most of the few studies were performed by workers who measured primary productivity in other parts of the Gulf of Guinea. Bessonov and Fedosov (1965) studied daily primary productivity rates at five different stations in Ghanaian waters in May and October 1963 and reported values for carbon fixation varying between 300 mg and 2,600 mg C /m^2/day depending on the season. They obtained their highest values in October, during the time of the principal local upwelling and recorded their lowest values in May when conditions were less favourable. Mahnken (1969) carried out similar primary productivity studies at Cape Three Points, Ghana, from January to March 1963 and from July to August 1963. He obtained higher values of more than 1,000 mg C /m^2/ day over the latter period which again corresponded with the time of the local upwelling. Nellen (1969) also measured primary productivity rates in various parts of the Gulf of Guinea including two areas off the Ghanaian coast (Tema and Cape Three Points) between February and May 1964 and reported an average productivity value of 677 mg C /m^2/day for

the Ghanaian stations. Zeitschel (1969) measured the microbiomass (phytoplankton, zooplankton and bacteria) at Cape Three Points, the area around Takoradi and Tema, Ghana, between September 1963 and June 1964. He used the results as indicators of the productivity of the area and obtained values of more than 2.00(mg /m^3 dry weight off Cape Three Points and Tema. He attributed the high values of the microbiomass to intensive phytoplankton production and development of zooplankton.

Besides primary productivity studies some work has been done on the chlorophyll cycle in Ghanaian waters. Nellen (1969) and Zeitzschel (1969) undertook some chlorophyll a analysis during their various cruises and reported high values (1-5 mg/m3) for the Cape Three Points area and lower values of 0.5 - 1 mg/m^3 for the Tema area. There are no studies on the quantity and composition of the phytoplankton off the Ghanaian coast except Hendey (1958) who identified diatoms collected from Takoradi harbour.

Phytoplankton forms the base of the food chain in the open seas, therefore, their production can be related to fish production. This can be traced through a secondary level of productivity such as zooplankton which in turn provide food for fish larvae and some juvenile fish. Adult fish such as Sardinella feed directly on zooplankton (Kwei 1964) and Anchoveta

also feed on both phytoplankton and zooplankton (Bayliff 1963). Allen (1909) Iselin (1939) and Cooper (1948), have shown a correlation between fish abundance and those physical and chemical factors that affect primary production. Therefore the ultimate productivity of an area is directly related to the rate of primary production.

From the above account it is seen that knowledge of the phytoplankton cycle in Ghana is far from being complete. To understand the productivity of the Ghanaian waters, a whole year round survey of the phytoplankton, cycle and the factors affecting it is necessary. The present study was therefore undertaken with the following objectives:

a. To determine the seasonal changes in the composition as well as the productivity of the phytoplankton population.

b. To attempt to relate the seasonal changes in the phytoplankton population to various physico-chemical factors such as phosphate, nitrate, silicate, oxygen, temperature and salinity.

II. MATERIALS AND METHODS

The sampling site, station A1, is about 8 km South-West of Tema (05° 30'N 0●°00') where the sea floor is at a depth of approximately 30m (Fig.I).

The station was visited once a week between September 1973 and November 1974 although due to frequent breakdown of the research vessel at the beginning of the study period certain sampling dates were missed. Sampling normally took place at 0900 hrs. and in all 44 samples were taken during the study period. On each visit, water samples were taken from the following depths: surface, 5m, 10m, and 20m, using a 5-litre hydrobios Ruttner plastic water sampler, fitted with a main and an auxillary reversing thermometer. (Sampling at 5m was only commenced in March 1974). Temperatures were read directly and recorded in degrees celcius after making the necessary correction according to Sverdrup (1947) for protected thermometers. Subsamples were withdrawn for nitrate, phosphate, silicate, salinity and oxygen analyses. Another subsample was taken and preserved in Lugol's solution (Lovegrove 1960) for phytoplankton identification and count. The remainder of the sample was emptied into labelled plastic bottle kept in the dark and brought to the laboratory for chlorophyll a analysis. Whenever analysis was delayed

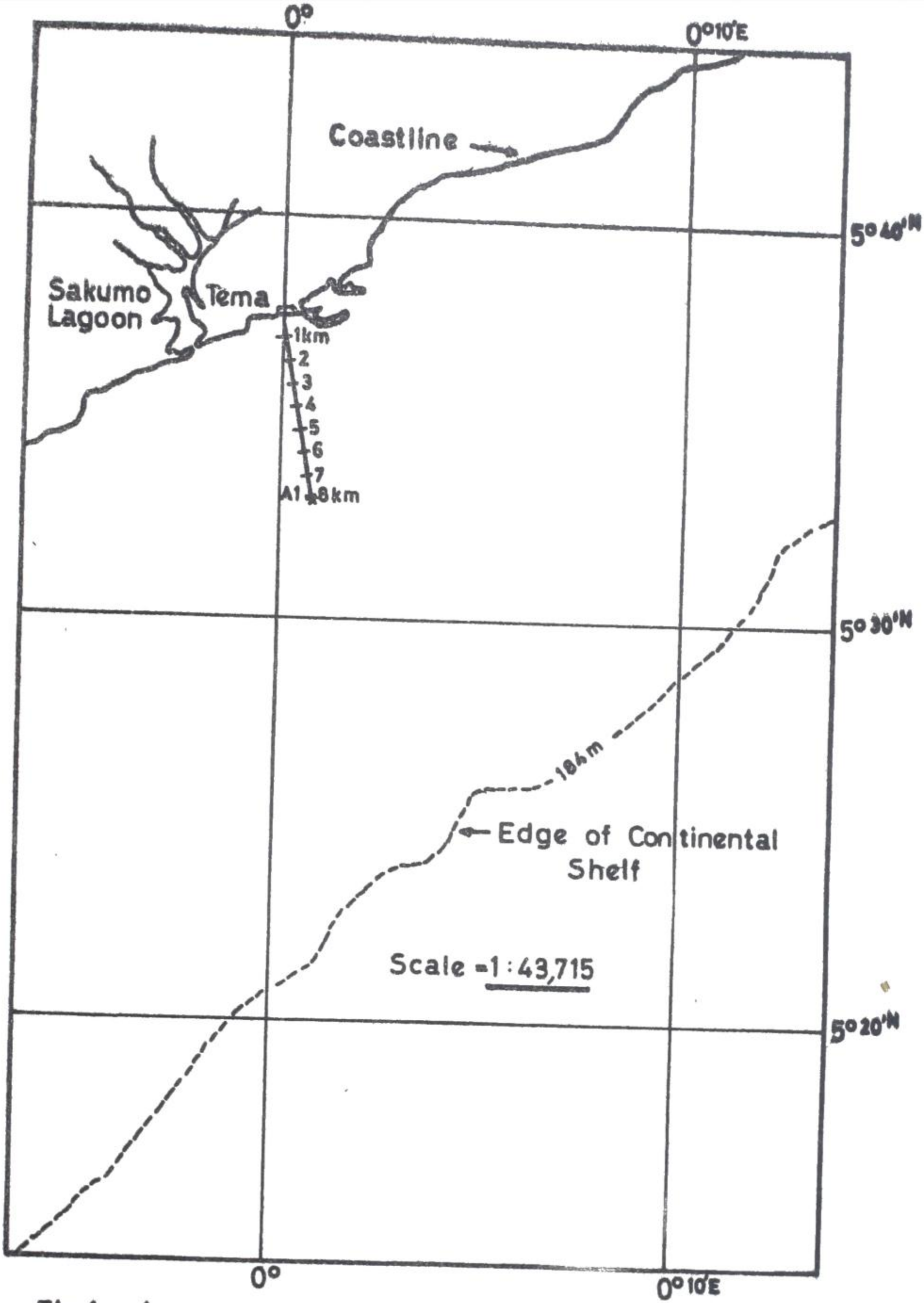

Fig.1 – A map showing the relationship of the sampling station (A1) to the coast near Tema.

the samples were refrigerated and allowed to attain room temperature before being analysed.

A Physico-Chemical analyses

(i) Dissolved Oxygen

The samples for the determination of dissolved oxygen were collected in 130 ml B.O.D. bottles taking care not to include air. These were immediately fixed with manganous sulphate and alkaline iodine solutions. Later on dissolved oxygen analysis was carried out in the laboratory according to the Winkler method described by Strickland and Parsons (1968). Analysis was done in duplicate.

(ii) Salinity

Salinity samples taken with salinity bottles were analysed in the laboratory using the Knudsen-Mohr silver nitrate-chromate titration method as modified by Strickland and Parsons (1965).

(iii) Phosphate

Phosphorus compounds exist in various forms in natural waters. The most important ones are the orthophosphates and polyphosphates. However, in the sea there is no evidence of the presence of polyphosphate though it has been found in some seaweeds (Armstrong 1965). Orthophosphates form the main soluble forms of phosphorus in the sea. (Armstrong 1965, Tait 1968). It is believed that

it is in this form that phosphates are taken by micro-organisms. In this analysis the total phosphate content was determined using the Stannous Chloride method described in "Standard Methods (1965)".

In this method all insoluble phosphates were hydrolysed into soluble orthophosphate. The basic principle of this method is that the phosphate ion combines with ammonium molybdate under acid conditions. This forms a complex compound known as ammonium phosphomolybdate. The molybdenum contained in the ammonium phosphomolybdate is readily reduced by the Stannous chloride to produce a blue coloured solution. Its intensity is proportional to the amount of phosphate present:

$(NH_4)3\ PO_4$ + 12 Mo●3 + Sn^{++} (Molybdenum blue)+ Sh^{++} The extinction of the sample against distilled water was read at 690 mμ on a Pye Unicam Sp. 500 spectrophotometer using a 10-cm cell. The concentration of total phosphate was read from a standard curve.

(iv)<u>Nitrate</u>

Inorganic nitrogen occurs as ammonia, nitrate and nitrite in sea water (Vaccaro 1965). Nearly all the combined inorganic nitrogen is in the form of nitrate (Harvey 1960). In this analysis reactive nitrate present in the sea water was determined according to the method described by Strickland and Parsons (1968).

In this method the nitrate was reduced to nitrite by running a mixture of the sea water sample and concentrated ammonium Chloride solution through a reduction column. The column was made up of cadmium filings loosely coated with metallic copper. The Nitrate formed was treated with Sulphanilamide solution and N-(1-Naphthyl) ethylenediamine dihydrochloride. The extinction of the sample against distilled water was read at the wavelength of 543 mμ on a Pye Unicam Sp. 500 spectrophotometer using 1-cm cell. A factor F for calculation was determined using potassium nitrate solution instead of sea water. The procedure was the same as the one outlined above.

(v) Silicate

Silicon in sea water is found in solution as silicate ions, also in suspension as silicon dioxide and as clay minerals (Armstrong 1965). In this analysis the reactive silicate present in the sea water sample was determined according to the method described by Strickland and Parsons (1968). 10 ml of ammonium paramolybdate solution was poured into a 100 ml measuring cylinder, fitted with a glass stopper. Into this was then pipetted 25 ml of the sample which had been stored in a polyethylene bottle. The mixture was allowed to stand for 10 minutes for the development of a silicomolybdate complex. After this time 15 ml of a reducing agent was added making the volume up to

50 ml. The extinction of the solution against distilled water was read at a wavelength of 810 mμ on Pye Unicam Sp. 500 spectrophotometer using a 1-cm cell.

A reagent blank for the correction of the readings observed was determined, during the analysis of each batch of samples, using 25 ml of distilled water stored in a polycthylene bottle.

A factor F for the calculation of silicate was determined by means of the method outlined above using 25 ml of dried sodium silico-flouride solution which has been further diluted with synthetic sea water (sodium chloride and magnesium heptahydrate solution).

B. Phytoplankton studies

(iv) Cell count and identification

A modified form of the sedimentation method described by Lovegrove (1960) was employed. Sea water samples of 50 ml from the various depths were preserved with Lugol's solution and kept in labelled bottles. In the laboratory the samples were allowed to stand in the dark for a day to allow for good prescrvation. The samples were well shaken to distribute the cells evenly. 1-ml subsample was pipetted out into a 1-ml counting chamber. The chamber was covered with a glass cover. The subsample was allowed to stand for one hour to allow the organisms to settle. The organisms were identified to the genus

level using various keys such as those found in Lebour (1925, 1930), Griffith (1961) and Tregoubo**ff** and Rose (1957), and counted along transects under an inverted binocular microscope. The number of phytoplankton organisms counted gave the population per ml and by conversion the population per litre was obtained.

(vii) Chlorophyll determination

Chlorophyll a concentration was determined according to the method described by Strickland and Parsons (1968). Two litres of sea water sample from each depth was filtered through a net of 300 µm mesh size to remove the larger zooplankton. The water was then filtered through a 40 mm millipore AA filter paper under pressure of 31.1 cm of mercury. 1 ml of magnesium carbonate suspension was added to the last few millitres of the sample being filtered so as to neutralise any acid that may be present or form later. The filter paper was then ground in 10 ml of 90% acetone and the ground sample was poured into a labelled and graduated centrifuge tube which was then stoppered.

Each sample was treated in the same way and the tubes were covered with aluminium foil to cut out light. The covered tubes and their contents were kept in a refrigerator for 20 hours to allow for complete extraction. After 20 hours the samples were removed from the refrigerator and placed on a table

to allow them to attain room temperature. Each sample was then centrifuged at 3,000 r.p.m. for 10 minutes. Absorbencies of the 90% acetone extract was read against 90% acetone at wavelengths of 750 mu, 665 mu, 645 mu and 630 mu on a Pye Unicam Sp. 500 spectrophotometer using a 10-cm cell. The samples were all run in duplicate.

The chlorophyll a concentration was calculate from the following formula deduced by Strickland and Parsons:

Total mg chlorophyll a = 11.6 x E665 - 1.31 x E645 - 0.14 x E630

$$\text{mg Chlorophyll a/m}^3 = \frac{\text{Total mg Chlorophyll a}}{V}$$

Where V is the volume of sea water filtered.

(viii) Primary production

The Carbon - 14 method was used to carry out in situ primary productivity studies. Once a month from July to November 1974 water samples were collected from the surface, 5 m, 10 m and 20 m depths in the manner described previously. The sample from each depth was immediately placed in a labelled polyethylene container and kept in the dark. Each sample was then filtered through a zooplankton net with a mesh size of 300 µm to remove large zooplankters. Two labelled 280 ml B.O.D. bottles, one light and one dark, were used for

each sample and filled with the respective sample. 10 microcuries of labelled sodium bicarbonate solution was introduced into each bottle by means of a syringe fitted with a long needle. The bottles were stoppered tightly, shaken to distribute the labelled bicarbonate and suspended at the depth from which their contents were collected. After 4 hours of incubation the samples were removed from the water and a few drops of formalin were added to the contents of each bottle to stop any further biological activity. The samples were taken to the laboratory. After shaking, 10 ml of each sample was filtered through a 15 mm Ha millipore filter paper. The filter paper was allowed to drain dry and then washed with sea water which had been filtered through millipore filter paper to remove all particles. The filter paper as allowed to drain dry again and put into a labelled liquid scintillation vial 10 ml of liquid scintillation fluid (NE 233) was added to each vial. The activity was counted in a Packard Liquid Scintillation Counter (314 x E Tricomb). Total count for the enti:c sample was calculated and used in the final calculation. On each occasion the total alkalinity, pH, and temperature of the water sample were determined.

Photosynthesis in mg C $/m^3$ hr. was calculated using the following formula:

$$P = \frac{(Rs-Rb) \times C \times f}{R \times t}$$

Where P = photosynthesis = mg $C/m^3/hr.$

Rs = uptake of radioactive carbon in count/min as recorded from sample.

Rb = Incubation time (hrs.)

R = Total available carbon in count/min:

= Microcuries used x efficiency of counter.

C = Total available stable inorganic carbon in mg/m^3 i.e. 12,000 x total alkalinity x ft

ft = 1.10 at pH 7, 1.0 at pH 7.7

f = isotope correction factor for the discrimination between C^{12} and C^{14} usually 1.06.

mg C $/m^3$/day was calculated and the results were used to calculate the total mg C $/m^2$/day by means of the following formula used at the Danish Institute of Fisheries and Marine Research and employed also by Reyssac (1970).

$$\text{mg C } /m^2/\text{day} = \frac{P1\ P2}{2}(p2' - p1) + P_2\ P_3(p3 - p2)$$

$$\frac{P_3\ P_4}{2}(p4 - p3) + \ldots\ldots$$

Where P1, P2, P3, P4, are the primary production in mg C $/m^3$/day at depth p1, p2, p3, p4.

III. RESULTS AND DISCUSSION

C. Physico-chemical factors

ix. Temperature and salinity

There were often marked changes in water

temperature at station A_1 between consecutive sampling times (Fig.2) with changes usually taking place along the whole of the water column. Drop in temperature between the surface and the 20 m depth varies between 0.1°C and so much as 3.5°C. This drop in temperature is usually a gradual one and only rarely is there a marked temperature discontinuity. For instance, there was a drop of about 3°C between the 10 m and 20 m depths in early December 1973 whilst a drop of 2.6°C was measured between the 5 m and 10 m depths on the 18th of July 1974. Water temperature showed a very definite seasonal fluctuation with values above 25°C being normally recorded from the end of October to the end of June whilst during July - October (the rainy season) temperatures below 24°C were recorded at all depths. Much lower temperatures (<20°C) were sometimes recorded for the 10 m and 20 m depths over the latter period. Beside the rapid fall in water temperature measured at all depths in July, there was also a small drop between December and January.

Salinity fluctuations were small and when they occurred they were uniform along the water column with little difference being found between the depths

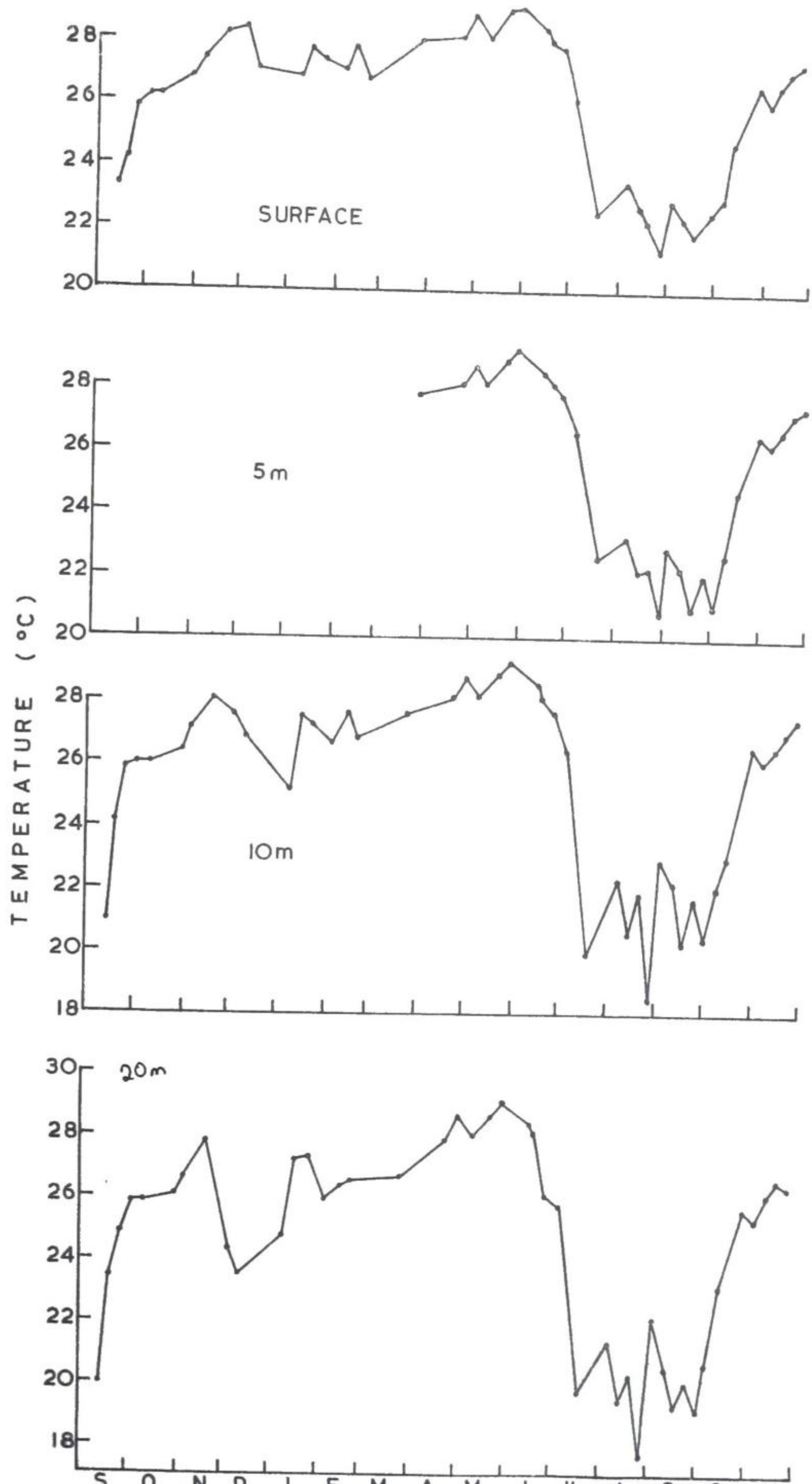

Fig. 2 – Weekly changes in water temperature at four depths at station A_1 off Tema.

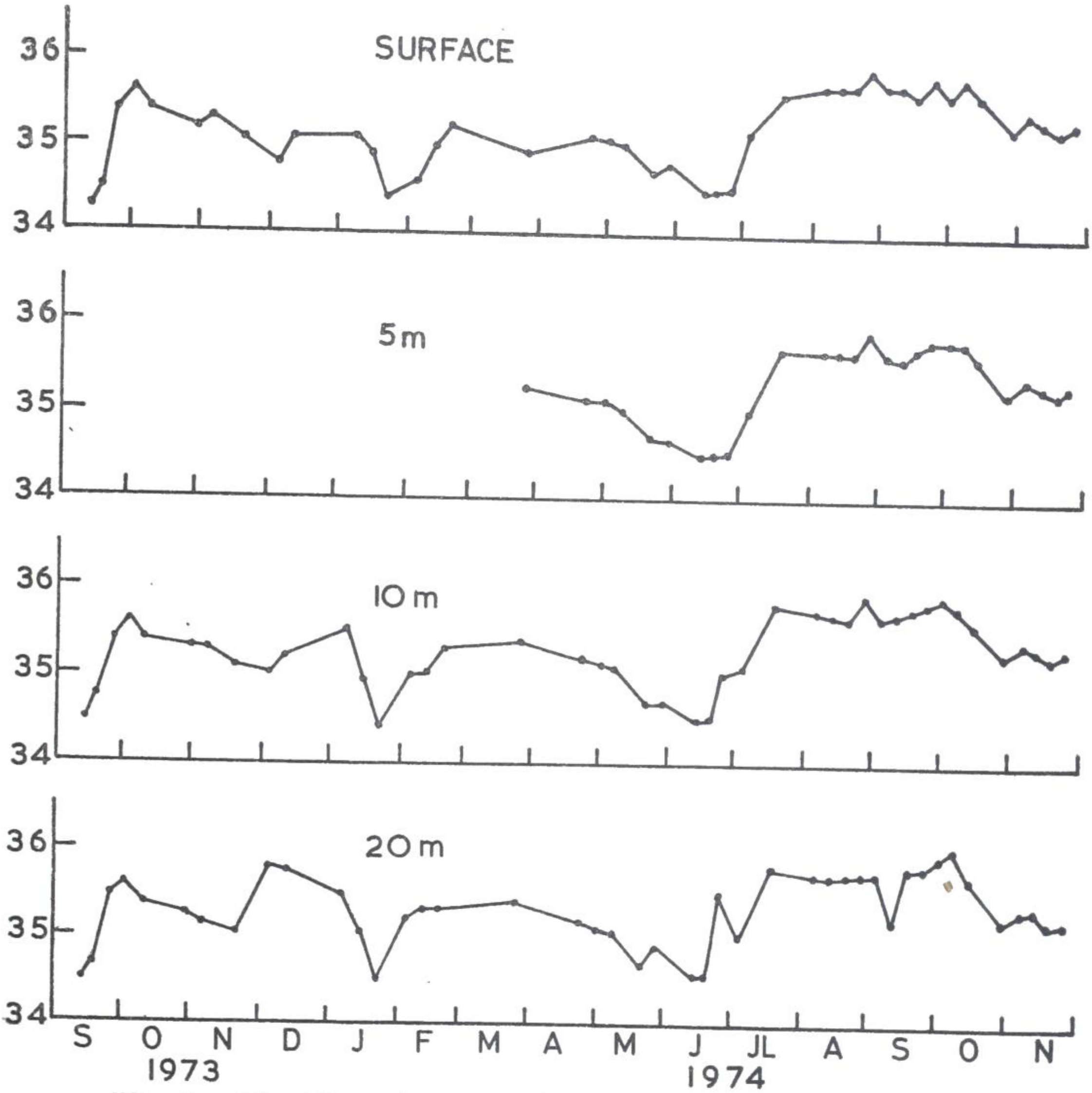

Fig. 3 — Weekly changes in salinity at four depths at station A_1 off Tema.

at which measurements were taken (Fig.3). The salinity was below 35‰ from the middle of May to the end of June when the water temperature was generally above 27°C. Between July and the end of October salinity values were above 35‰ and decreased once again as temperature increased. It is interesting to note that when temperatures as low as 24.4°C, and 23.6°C were recorded at 20 m on the 4th and the 11th of December respectively, high salinity values (35.8‰) were recorded as compared to the shallower depths where the temperatures were higher.

(xi) Dissolved oxygen

The dissolved oxygen values fluctuated between about 3.4 and 8.9 mg O_2/l) over the study period (Fig.4). The oxygen values decreased from the 14th of June to the 18th of July 1974 at all depths and then increased again by the 6th of August with the highest values (> 8 mg O_2/l) measured over the study period for the 0, 5 m, and 10 m, depths being recorded on the 20th of August. This peak was followed by a sharp fall to the lowest seasonal values (< 5 mg O_2/l) being recorded for the 10 m and 20 m depth on the 27th of August. After the 27th of August the values rose again at all depths on the 3rd of September, and fell once again by the

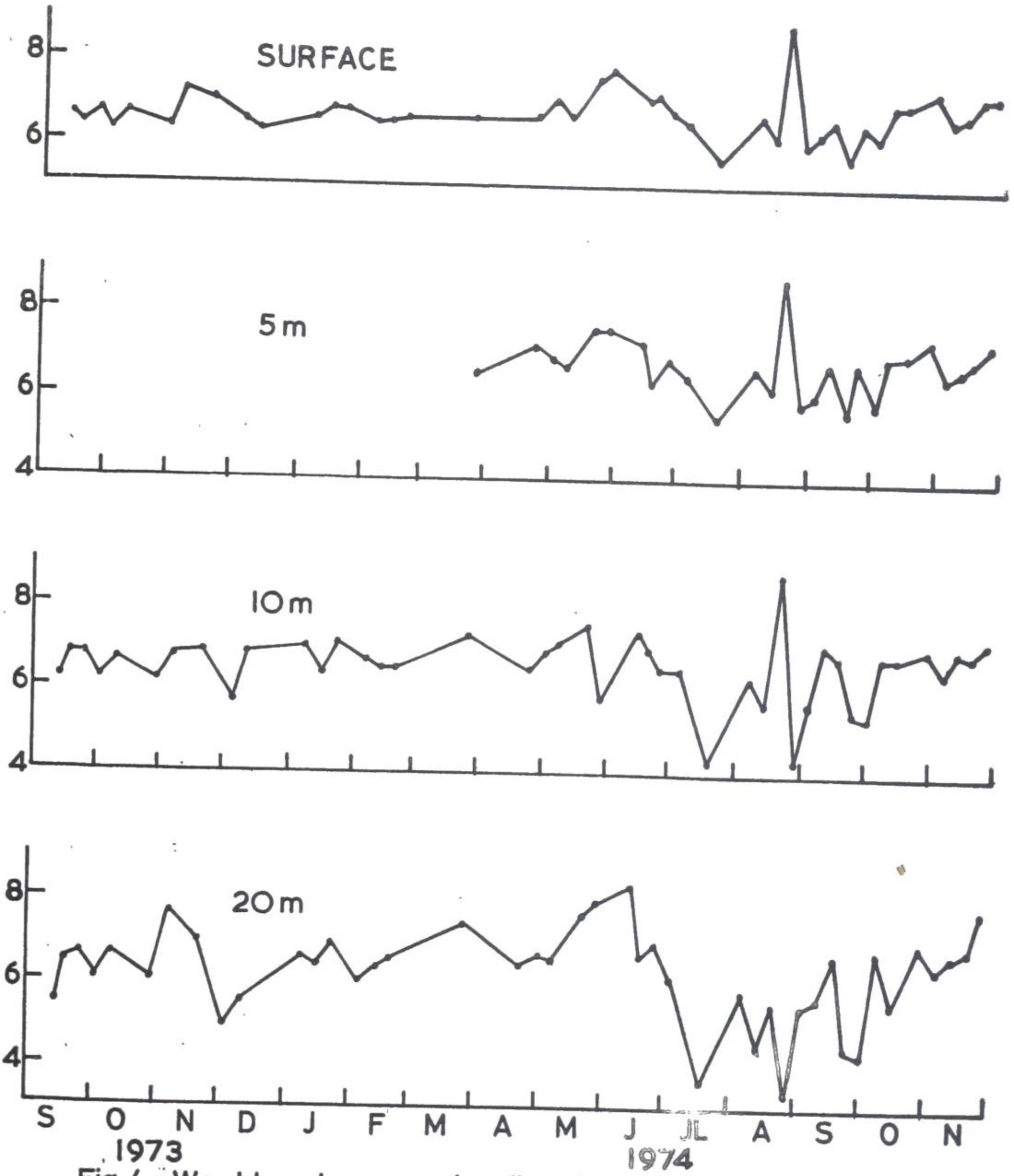

Fig.4—Weekly changes in dissolved oxygen at four depths at station A1 off Tema.

1st of October. By the 8th of October the oxygen values were above 6 mg O_2/l at all depths and remained so until the end of the study period. The highest oxygen value (8.4 mg O_2/l) observed for the 20 m depth was recorded on the 14th of June instead of the 20th of August. Moreover oxygen values for this depth between July and October were generally much lower (< 6mg O_2/l) than those measured at the shallower depths. In December 1973 the oxygen values dropped below 6 mg O_2/l at 10 m and 20 m and this corresponded to a similar drop in both temperature and salinity (see Figs. 2.3).

(xi) Total phosphate

There were clear fluctuations in the total phosphate values measured at different times throughout the study period. These fluctuations were not always uniform for all the depths studied on the same sampling occasion (Figs. 5, & 6). The average phosphate concentration rose from September 1973 to a peak between December and January at all depths (Fig.5). This was followed by a sharp decreases to March 1974 at the 10 m and 20 m depths. There was a second but smaller peak in April and May for the 20 m depth before low values were reached in June. There was a very sharp rise in the value for

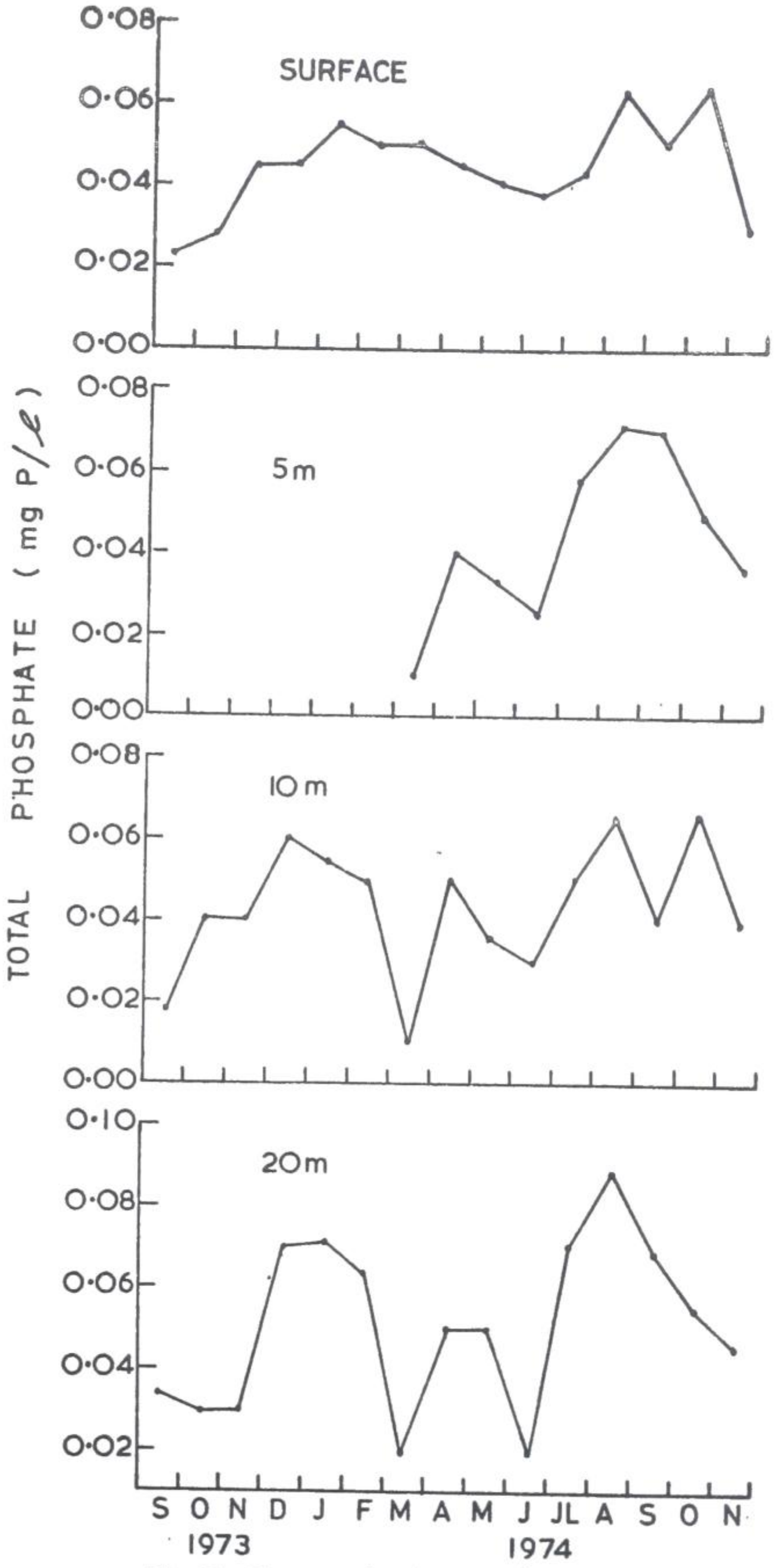

Fig. 5 - Seasonal changes in average monthly total phosphate concentration at four depths at A1 off Tema

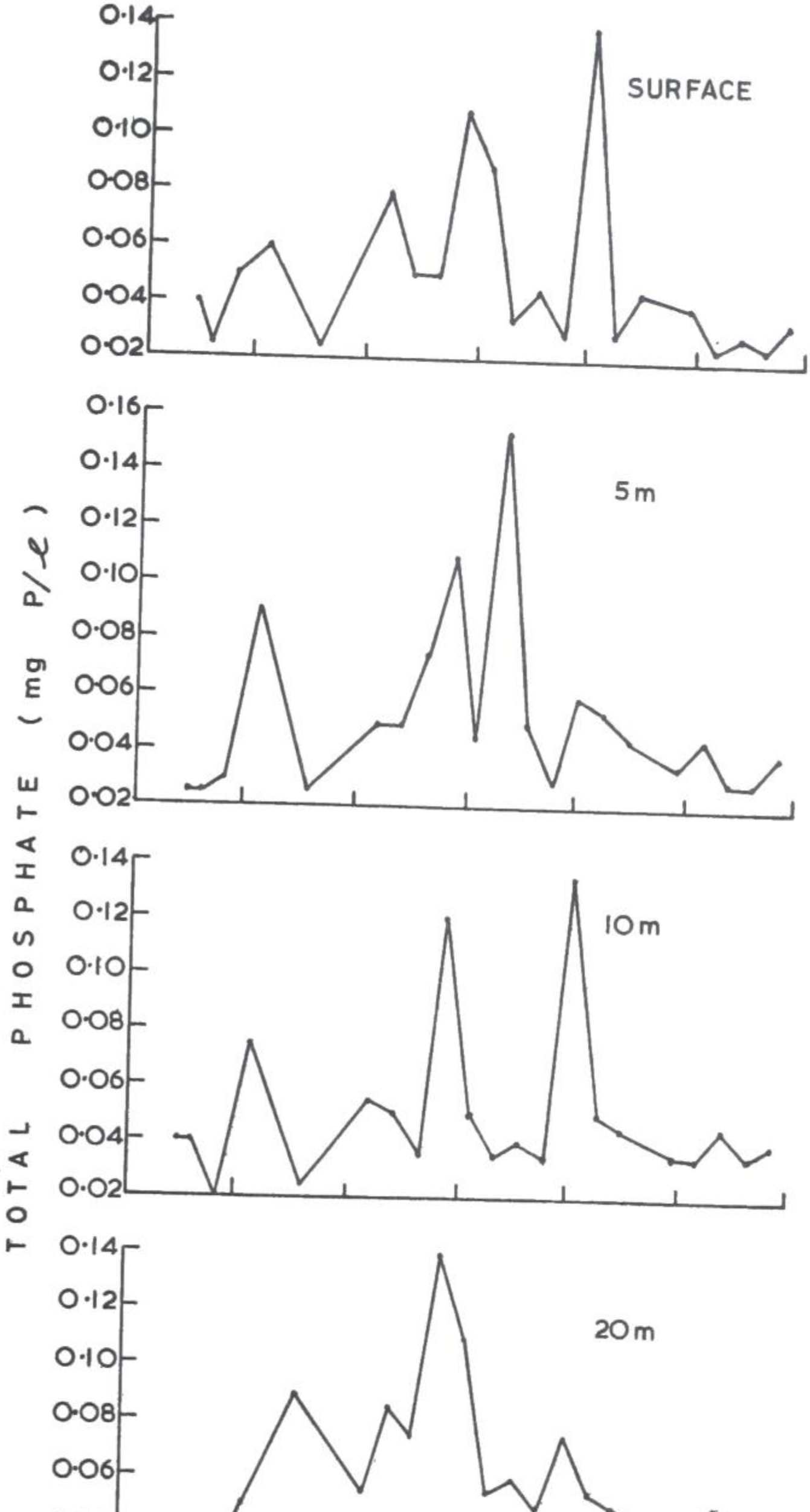

Fig. 6—Weekly changes in total phosphate concentration at four depths at station A_1 off Tema (June – November 1974)

total phosphate in July and a peak was reached in August for both the 10 m and 20 m depths. The fall after August continued until the end of the study period for the 20 m depth but for the 10 m depth there was another peak in October. At the surface the fall from February was gradual until June then there was a rise in July until a peak was reached in August.

During the rainy season there was often large weekly changes in phosphate concentration with peaks between 0.06 and 0.09 mg P/l being found between the surface down to the 10 m depth, on the 4th of July (Fig.6). This peak was followed by a decrease to below 0.03 mg p/l by the 18th of July whilst at the peak 20 m the peak for July (0.09 mg P/l) was now reached. Another peak in phosphate concentration was found on the 6th and 13th of August at all depths except 5 m. Another peak in phosphate concentration (> 0.1 mg P /1) was found on the 27th of August at all depths and this was higher than the previous ones. A rapid drop in phosphate now occurred and levels below 0.06 mg P/1were measured on the 10th of September for all depths except the 5 m depth where the highest concentration of phosphate measured over the study period (0.155 mg P/1) was recorded. Another peak in phosphate concentration was measured

on the 1st of October although this was only very pronounced at the surface and 10 m where values of 0.145 and 0.135 mg P/l respectively were recorded. After the 1st of October to the end of the study period values remained below 0.05 mg P/l at all depths.

(xii) Nitrate

The average nitrate concentration decreased from September 1973 to October 1973 at the surface and 10 m depths and then increased again to a peak of over 3 µg - at N/l by December (Fig.7). At the 20 m depth there was a decrease from September until January when the peak was reached. Nitrate concentration fell below 1.5 µg - at N/l in February at the 10 m and 20 m depths and remained above 2 µg - at N/l but below 2.5 µg - at N/l at the surface. There was a rapid increase to a peak of about 5 µg - at N/l at the 20 m in March and April whilst smaller peaks of 2.6 and 2.2 µg- at N/l were observed for the 5 m and 10 m respectively. The peak for the surface was observed in April and the one for the 10 m was observed in May. The lowest seasonal average value (0.5 µg - at N/l) was observed at all depths in June 1974. There was an increase to a peak in July and August and then, a drop in

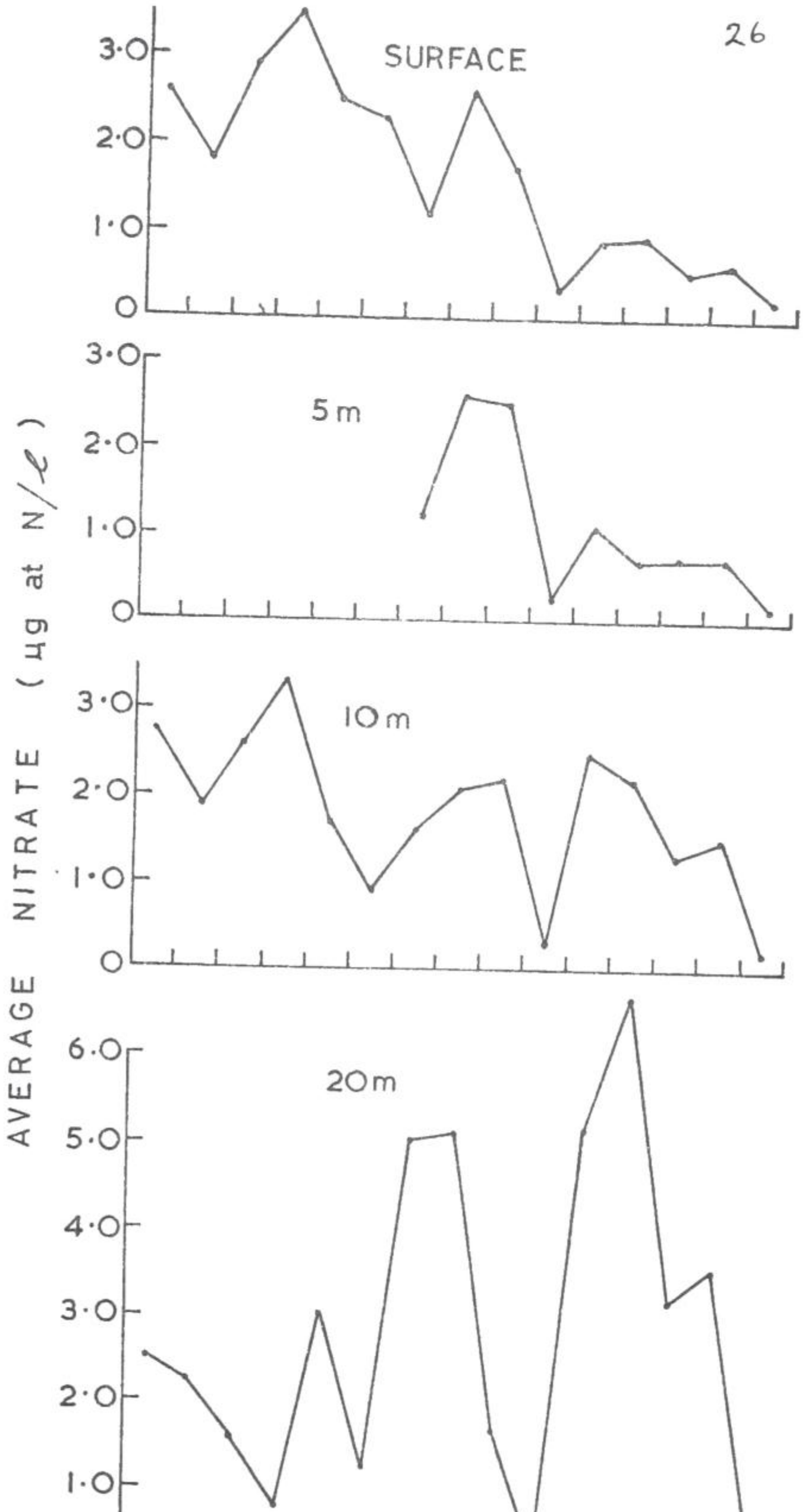

Fig. 7 – Seasonal changes in the average monthly nitrate concentration at four depths at station A1 off Tema

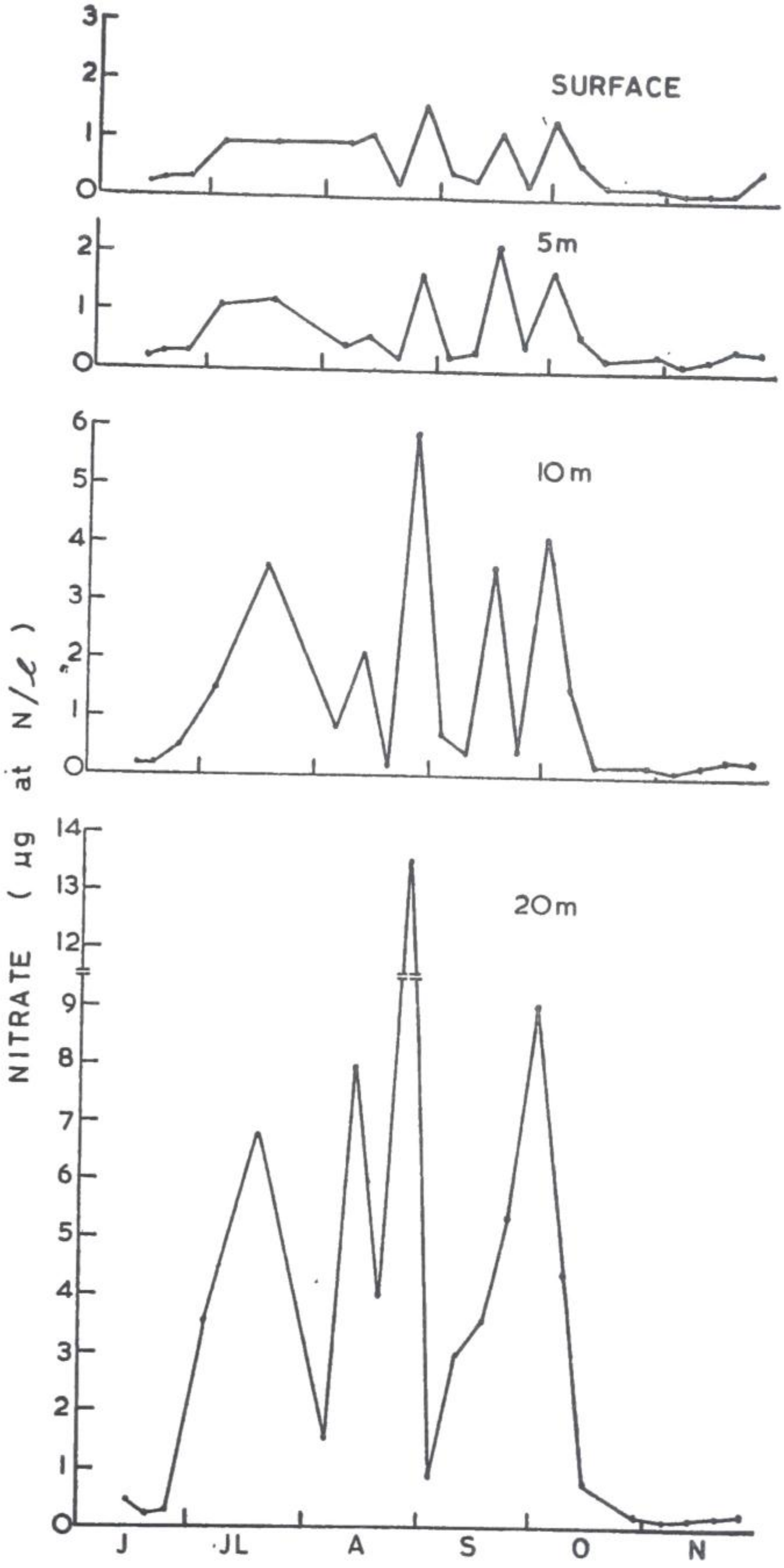

Fig. 8 – Weekly changes in nitrate concentration at four depths at station A_1 off Tema (June — November 1974)

September 1974 followed by a small increase in October and finally a fall again in November. The changes that occurred after June were more pronounced at the 10 m and particularly at the 20 m depth.

During the rainy season there were weekly uniform fluctuations in nitrate concentrations at all depths (Fig.8). There was a rapid increase in nitrate concentration in July until a peak (> 3.0 µg - at N/l) was reached on the 18th of July at the 10 m and 20 m depths. This was followed by a drop to below 2.0 µg - at N/l on the 6th of August followed by another peak on the 13th of August. These fluctuations were not detected at the surface and 5 m depths. Nevertheless, high concentrations of nitrate were recorded on the 27th of August at all the depths sampled, with the concentration at 20 m being early three times that at 10 m which in turn was more than twice of that found at 5 m and the surface. A rapid decline in nitrate values was found on the 3rd of September at all depths and another peak was measured on the 17th of September at all but the 20 m depth. The values were low again on the 24th of September at all but the 20 m depth but there was a sharp increase again so that by the 1st of October a final peak was found at all depths. By the 8th of October the value had fallen again and from the 15th

of October to the end of the study period the values remained below 1.0 µg - at N/l. The peaks in nitrate concentration at any one sampling time were usually progressively higher with increase in depth.

(xii) Silicate

There was a pronounced seasonality in silicate concentration with changes in its concentration over the study period showing a similar pattern and order of magnitude at all the sampled depths (Fig.9). The annual peak in silicate concentration was measured in January and February 1974 when average values were above 110 µg - at si/l. Much lower values between 10 and 25 µg - at Si/l were found in March and April at all depths. After this the values remained between 25 and 50 µg - at Si/l until October 1974 and then fell below 20 µg - at Si/l in November at all depths.

Large fluctuations in silicate concentration were found over the rainy season of the year (Fig.10). There were a number of peaks over this period with the two most pronounced ones occurring on the 18th of July (60 µg - at Si/l) and on the 3rd of September (45 µg - at Si/l)at all depths but the peak in September was less pronounced at the surface. There were smaller and less pronounced peaks

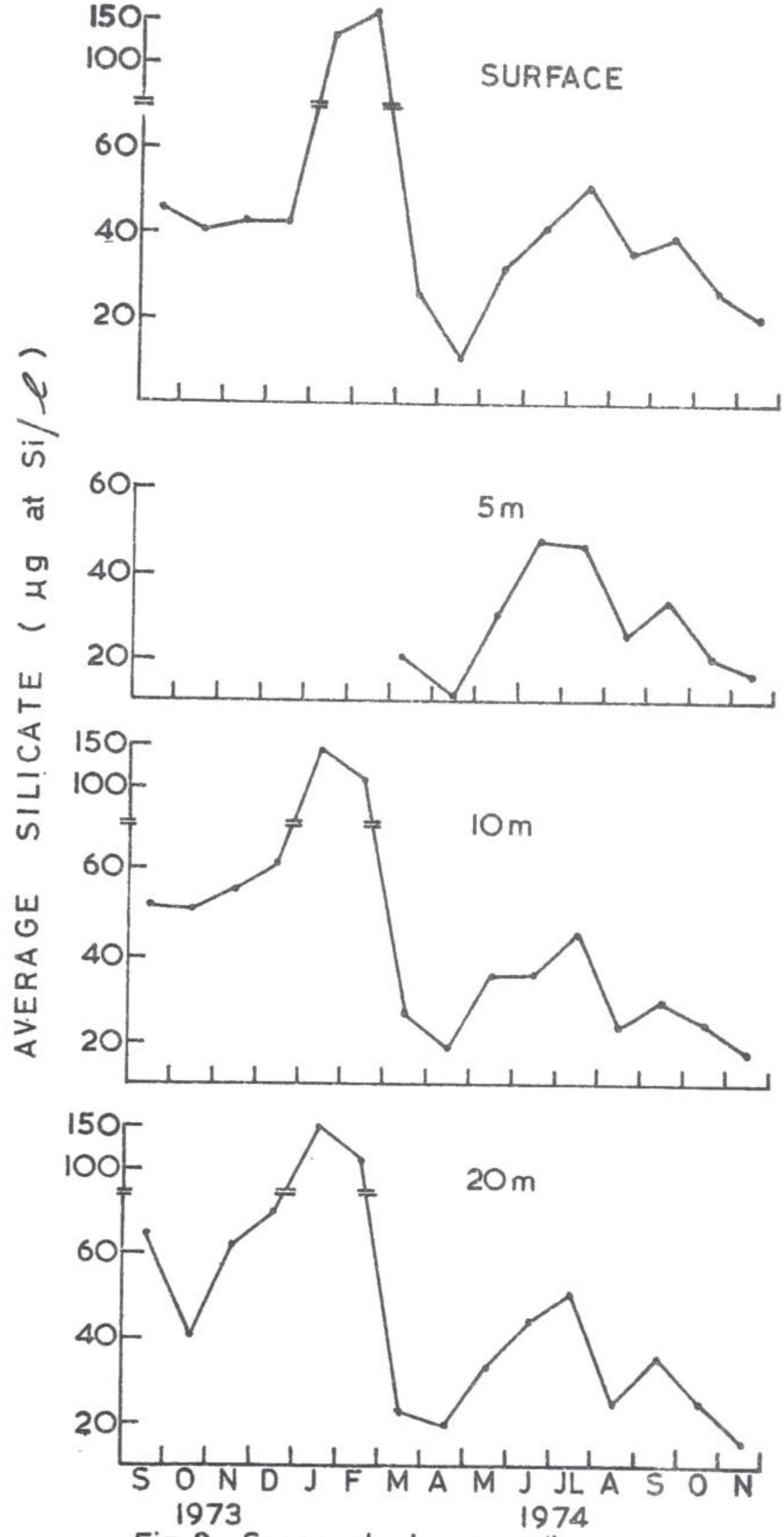

Fig. 9 – Seasonal changes in average monthly silicate concentration at four depths at station A1 off Tema.

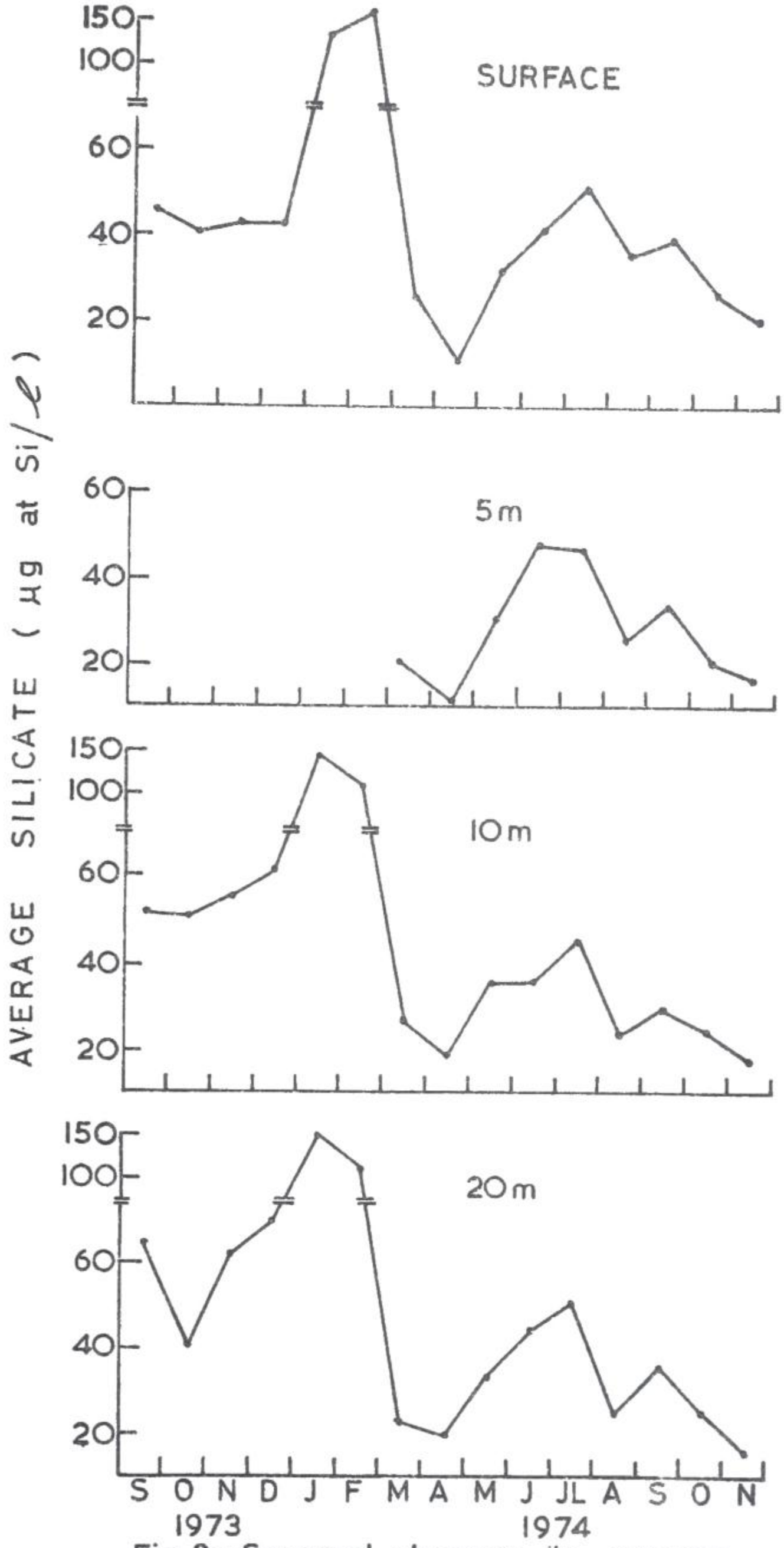

Fig. 9 – Seasonal changes in average monthly silicate concentration at four depths at station A1 off Tema.

after the 3rd of September to the end of the study period when the concentration remained below 45 µg-at Si/l.

(xiv) Discussion

Tropical regions are generally poor in nutrients except on the western side of continental land masses where there are regions of upwelling of colder and nutrient-rich water. (Russel-Hunter 1970, Gunther 1936). This nutrient-rich water caused an increase in biological productivity in the area. The surface water of the Gulf of Guinea, which the coast of Ghana borders, is generally warm and of low salinity (> 25°C, ~S 35‰). Nevertheless, in the rainy season (July-October) when the ambient air temperature is low, rainfall and cloud cover at a maximum and solar radiation at a minimum, then minimum annual water temperatures are recorded. The sudden drop in water temperature found in the present study off Tema at station A_1 (see Sig.2) corresponds to the beginning of this period. This is also the time of the year when a major upwelling normally occurs along the coast of Ghana. (Ingham 1970, Longhurst 1964). Weaker and more limited upwellings are known to occur between December and February and might account for the drop in water temperature measured in December. A number of

theories have been put forward to account for the upwelling along the Gulf of Guinea coast (Ingham 1970, Houghton 1973, Iople and Mensah 1971), but none gives a completely satisfactory explanation of the phenomena.

The water temperature measurements usually show a small decrease in temperature with depth and the absence of a distinct thermocline. This may explain at least in part, why the values for the physico-chemical factors often vary but little along the depth of the water column measured. However at times there are large differences especially in phosphate and nitrate (Figs. 6 & 8), in samples taken on the same occasion at different depths. Such differences might reflect distribution of phytoplankton organisms (see general discussion). For instance, it is often found that the concentration of phosphate is greater at the 20 m depth than in shallower waters.

There are seasonal changes in the concentration of phosphate, nitrate and silicate at all depths sampled (see Figs. 5, 7& 9). There are often marked weekly fluctuations particularly over the time of the year when the sea temperature is below 25°C and salinity is 35‰ or above. The nutrient concentrations were high between December 1973 and January 1974 which was when there appeared to be

a small upwelling. The highest nutrient concentrations were often measured for short periods from July through to October which is during the major upwelling season. In-flow of nutrient-rich water from the nearby lagoons such as Sakumo Lagoon (see Fig.1) into the sea during the rainy season might contribute to this increase. Nevertheless, the increase in salinity over this period of the year suggests that inflow of brackish lagoon water may not contribute appreciably to the high nutrient concentration. During the minor upwelling in December, as indicated by a drop in water temperature and increase in salinity particularly at 20 m, there was a sudden increase in nutrient concentration. This confirms the contention of Ingham (1970) who lists the appearance of more saline, colder and high phosphate concentration water, as indicative of upwelled water. Recently Reyssac (1970) has similarly found such seasonal changes in the physico-chemical environment off-shore in the neighbouring Ivory Coast.

D. Phytoplankton

(xv) Composition & cell count

Monthly average cell count of more than 20 x 10^3 cells/l was recorded in September and October 1973 at the surface and 10 m depth (Fig.11) followed by another

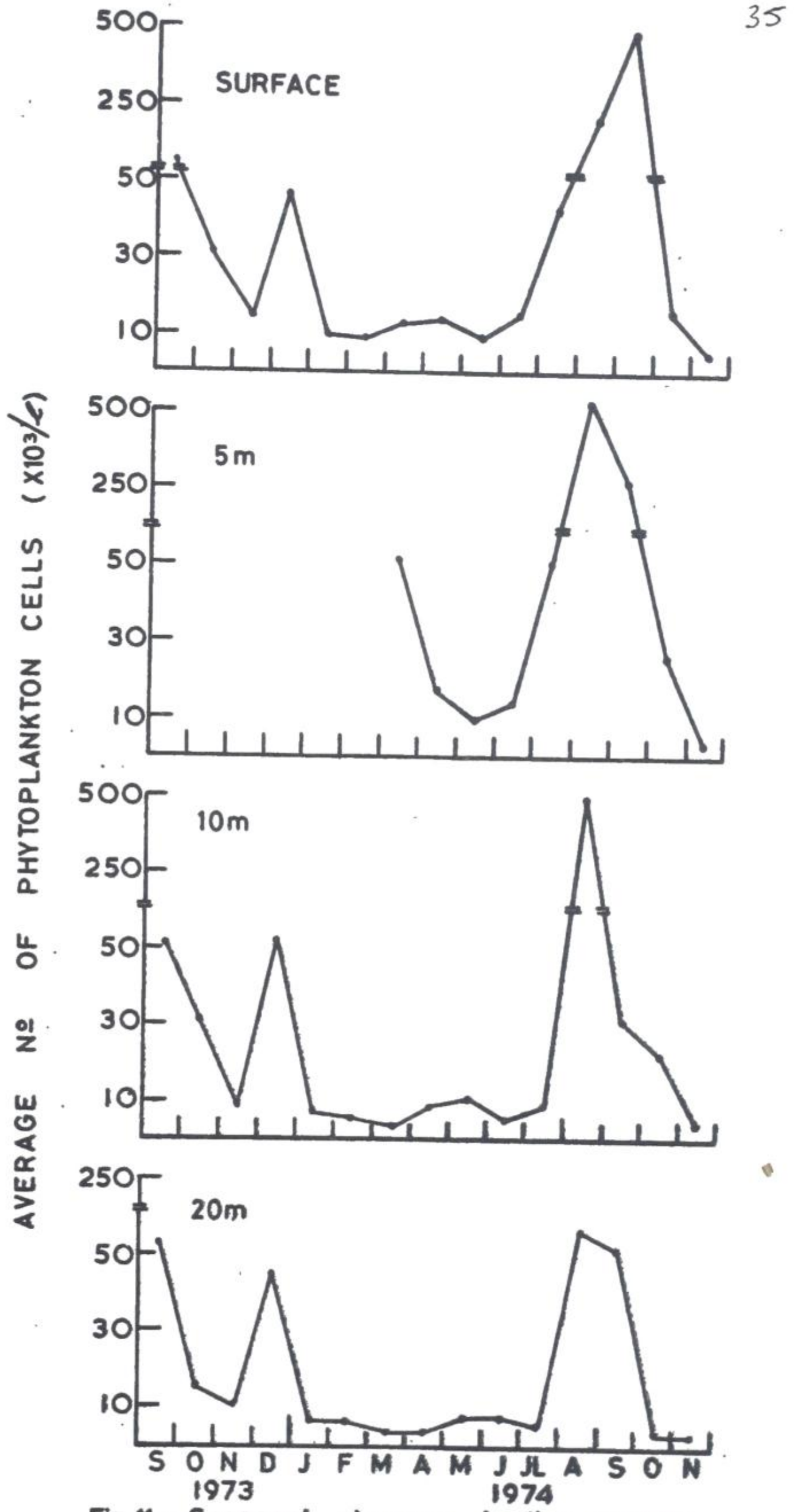

Fig. 11 – Seasonal changes in the average number of phytoplankton cells at four depths at station A_1 off Tema

peak at the surface, 10 m and 20 m in December 1973. Another high cell count (> 100 x 10^3 cells/l) was recorded between August and September 1974 at all depths. For the rest of the study period cell counts remained low (< 20 x 10^3 cell/l) except in March when cell count at the 5 m depth was above 60 x 10^3 cells/l and July when cell count at the surface and 5 m was above 40 x 10^3 cells/l.

Marked weekly fluctuations in phytoplankton cell numbers occurred between July and November 1974. (Fig.12). There was a rapid increase in the population after the 4th of July 1974 at the surface and 5 m. This resulted in a peak in cell numbers (> 100 x 10^3 cells/l) on the 18th of July 1974 at 5 m and a peak (> 150 x 10^3 cell/l) on the 6th of August 1974 at the surface. A rapid drop in cell numbers occurred between the 6th of August and the 13th of August with cell counts being below 20 x 10^3 cells/l at all of the depths sampled. After this drop a phytoplankton bloom now occurred at all depths on the 20th of August when cell numbers rose to above 1,800 x 10^3 cells/l at 5 m and 10 m only to be followed by an equally rapid decline to low cell numbers on the 27th of August. After this major peak in cell numbers at all depths, except the surface, there was another

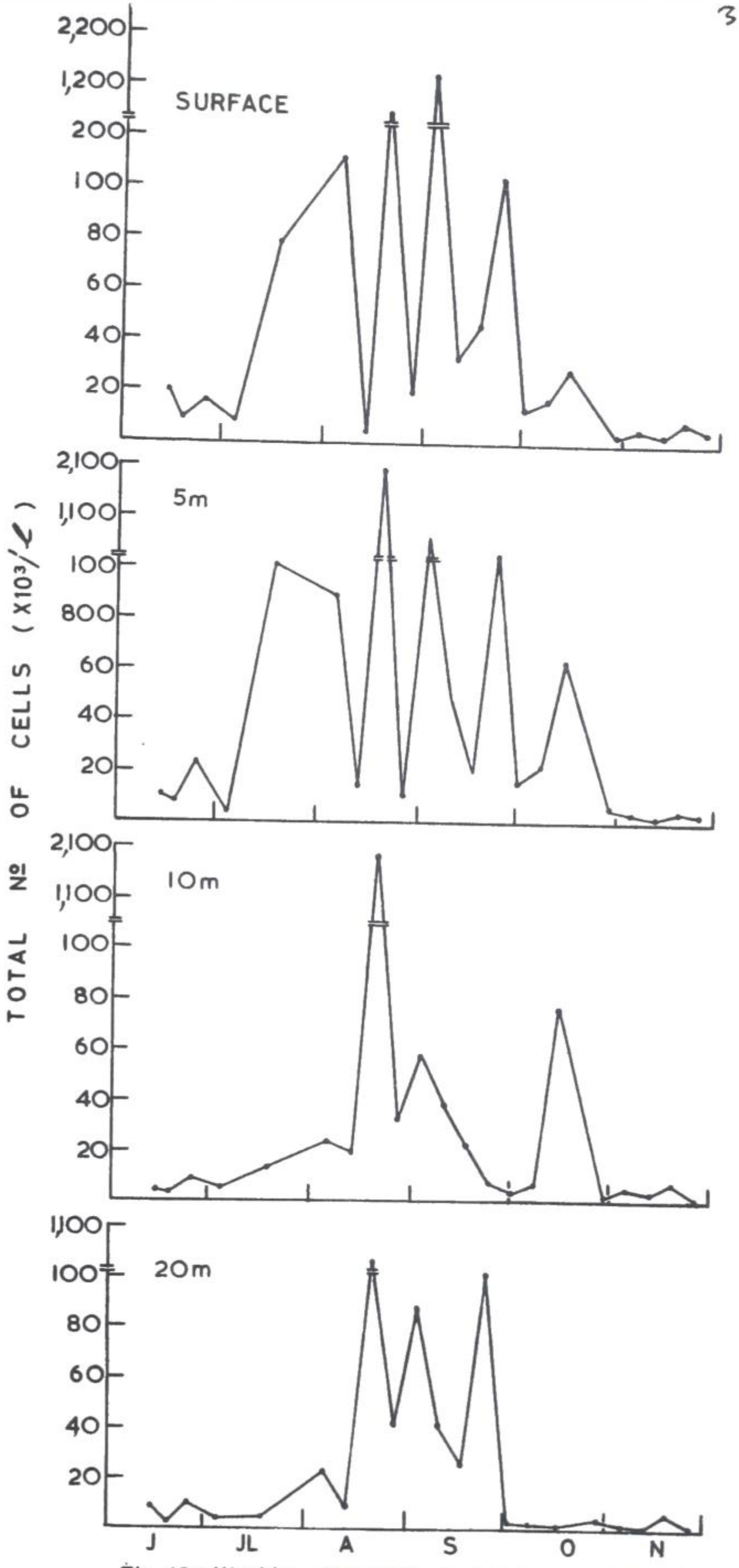

Fig. 12– Weekly changes in total number of phytoplankton organisms at four depths at station A_1 off Tema. (June — November 1974)

peak in cell numbers on the 3rd of September 1974. The organisms at the surface (1,466 x 10^3 cells/l) caused a reddish colouration of the sea and most of this cell count was the ciliate Mesodinium rubrum which, although not an alga, is nevertheless a functional autotroph as it contains algae as endosymbionts. If the count of this ciliate is ignored then the number of algal cells (23 x 10^3 cells/l) are similar to those found at 5 m. (19 x 10^3 cells/l). There was a decline in cell counts by the 10th and 17th of September at all depths. The final peak (about 100 x 10^3 cells/l) of the study period for the surface and 20 m was observed on the 24th of September. A peak in cell numbers also occurred at 5 m on the 24th of September but at this depth and 10 m a final peak was observed on the 15th of October. Cell counts remained below 10 x 10^3 cells/l from the end of October to the termination of the study.

Apart from quantitative changes there were also qualitative changes in the phytoplankton population throughout the year (Fig.13). The dinoflgellates formed between 50% and 90% of total cell counts between November 1973 and May 1974 when water temperature was above 25°C. In December however diatoms predominated forming as much as

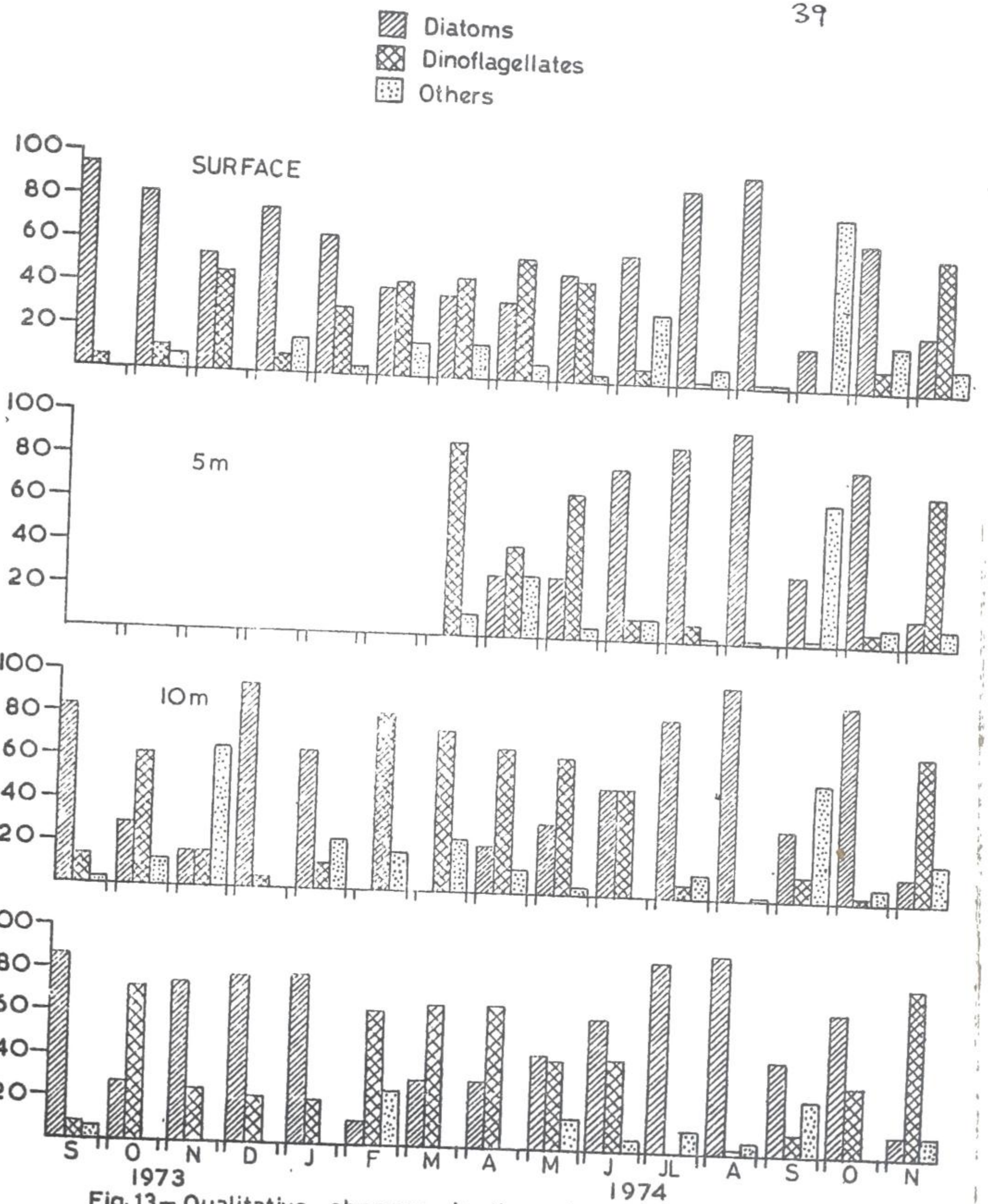

Fig. 13 – Qualitative changes in the phytoplankton at four depths at station A_1 off Tema.

90% of the total number of phytoplankton organisms at 10 m. In November 1974 more than 60% of the phytoplankton population was made up of dinoflagellates at all depths. The dinoflagellates consisted of such genera as Peridinium, Ceratium, Prorocentrum and Dinophysis with the dominant genera over the November to May period normally being Ceratium and Peridinium (see appendix I). Nevertheless, the diatoms were dominant interms of cell numbers between June and October when more than 50% of the total number of cells were diatoms. In August as much as 90% of the population at all depths were diatoms. The diatom flora over the period of low water temperature ($< 25\ ^{o}C$) included such genera as Skeletonema, Nitzschia and Thalassiosira. These genera were codominant for much of the time. In September 1974 the dominant component of the cell population at the surface was the ciliate Mesodinium rubrum. This was found in very large numbers on this one sampling occasion when it was largely confined to the top of the water column.

(xvi) Chlorophyll concentration

The average chlorophyll a concentration at the surface increased from 0.13 to 0.20 mg Chl a/m^3

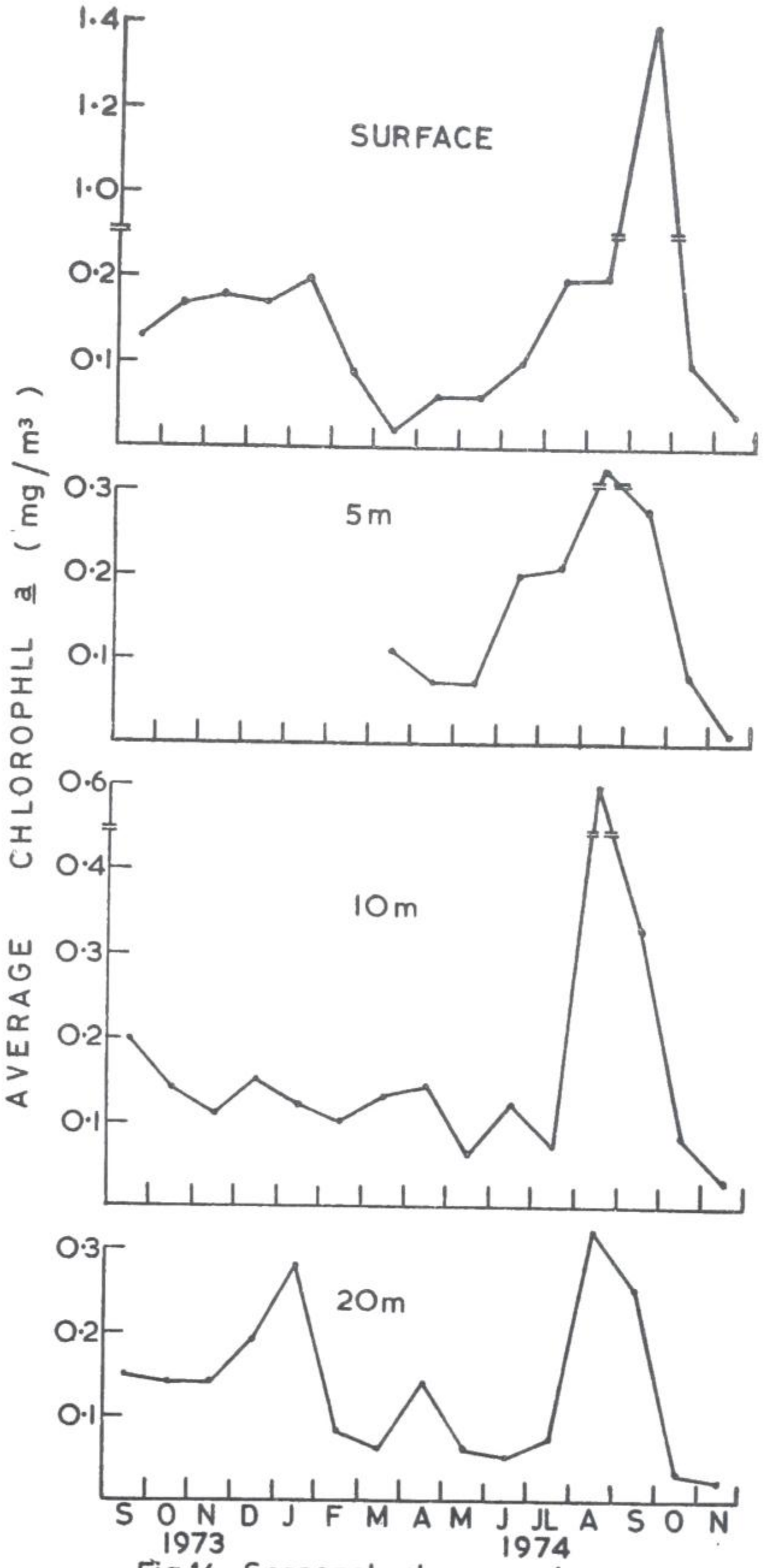

Fig.14– Seasonal changes in average monthly chlorophyll a concentration at four depths at station A1 off Tema.

between September 1973 and January 1974 (Fig.14). There was a decrease from February until the lowest value of 0.20 mg Chl a/m3 was measured in March. This was followed by an increase in April which was maintained until September 1974, when the highest value of 1.41 mg Chl a/m3 was obtained. There was a sharp fall after this peak and the values remained below 0.1 mg Chl a/m3 in October and November 1974. The pattern for the 5 m depth was similar to that of the surface but the highest peak (0.43 mg Chl a/m3) was now in August instead of September. In contrast, at the 10 m depth there were fluctuations in Chlorophyll a values (0.06-0.2 Chl a/m3 between September 1973 and July 1974. The highest peak (0.6 mg Chl a/m3) was obtained in August 1974. After this peak the value declined in September and by October and November the values were below 0.1 mg Chl a/m3. Values for the 20 m depth followed similar rises and falls as measured at the surface but the rise in April was followed by a fall and the highest value (0.32 mg Chl a/m3) was obtained in August instead of September 1974.

There were marked weekly fluctuations

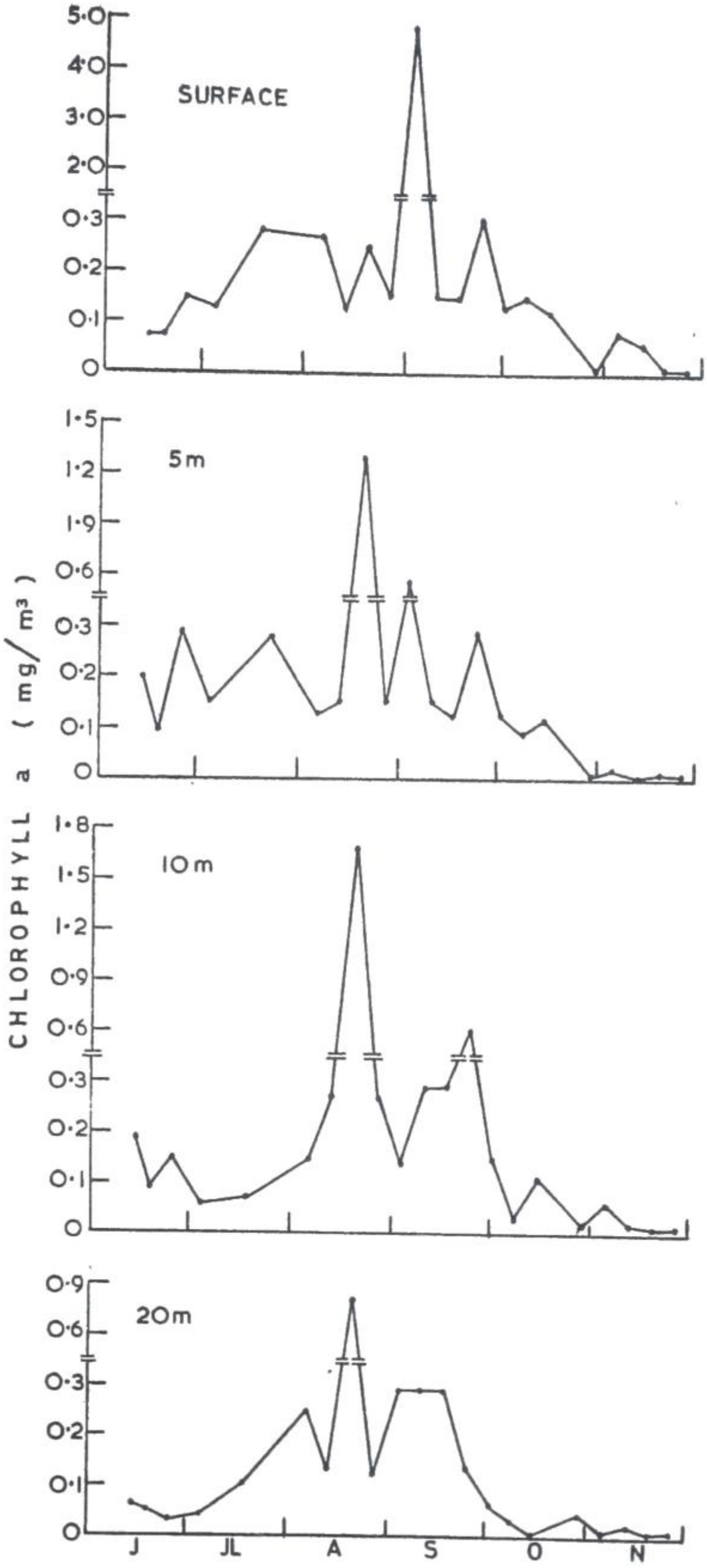

Fig. 15 – Weekly changes in chlorophyll a at four depths at station A_1 off Tema (June – November 1974)

between July and November 1974. (Fig.15). The chlorophyll a concentration at the surface showed small fluctuations from the 18th of July until the 3rd of September when a sudden increase occurred and the highest value of the study period (4.9 mg Chl a/m^3) was obtained. This peak was followed by a fall and then another small increase on the 24th of September. After this low levels of chlorophyll a (0.2 mg Chl a/m^3) were measured until the end of the study period. The pattern for chlorophyll a concentration for the 5 m depth was the same as that of the surface but the highest peak (1.29 mg Chl a/m^3) was now observed on the 20th of August whilst smaller ones were found on the 3rd and 24th of September. There was a peak of 1.72 mg Chl a/m^3 and 0.8 mg Chl a/m^3 at the 10 m and 20 m depths respectively on the 20th of August. After this peak another small peak occurred on the 24th of September at the 10 m depth. After the 24th of September chlorophyll a values remained below 0.2 mg Chl a/m^3 at the 10 m depth and below 0.1 mg Chl a/m^3 at the 20 m depth. The most pronounced decline in chlorophyll a concentration occurred on the 27th of August at all depths except the surface

where the greatest drop occurred on the 10th of September. The highest chlorophyll a concentration was measured at the 10 m depth in August if the chlorophyll a results obtained during the presence of the high concentration of the ciliate Mesodinium rubrum are ignored. This was followed by the 5 m, 20 m and then the surface.

(xvii) Primary Productivity

The highest primary productivity rates were measured in August 1974 at 10 m (15.3 mg C /m^3/hr) and 20 m (17.3 c /m^3/hr) as shown in Table 1. The lowest value (0.9 mg c/m^3/hr) for the 10 m depth was obtained in September and that for the 20 m depth was obtained in October (0.5 mg C/m^3/hr). The highest values for the surface and the 5 m depth were both obtained in August but they were much lower (4-5 mg C /m^3/hr). The average primary productivity rate, over the upwelling period (July - October) for the surface and 5 m depth was less than 3.0 mg C /m^3/hr and this is about half of the average values obtained for the 10 m and 20 m depths (5.85 - 5.95 mg C /m^3/hr). The highest average values were similar at 10 m and 20 m depths (5.95 and 5.85 mg C /m^3/hr respectively) followed by 5 m and finally the surface. In November, which is outside the upwelling period, the productivity rates

TABLE I RATE OF PRIMARY PRODUCTION JULY - NOVEMBER 1974

Month	mg C /m^3/hr				mg C /m^3/day				mg C /m^2/day
	0m	5m	10m	20m	0m	5m	10m	20m	
July (24th)	0.8	2.3	4.2	2.8	19.2	55.2	100.8	67.2	1,416.0
August (23rd	4.8	4.12	15.3	17.3	115.2	98.8	367.2	415.2	6,001.1
September (24th)	1.6	0.9	0.9	2.8	38.4	21.6	21.6	67.2	746.0
October (21st)	1.6	3.8	3.4	0.5	38.4	91.2	81.6	12.0	1,270.0
Total	8.8	11.12	23.80	23.40	211.20	266.80	571.20	561.6	9,433.1
Average	2.20	2.78	5.95	5.85	52.80	66.70	142.80	140.4	2,358.3
November (27th)	1.0	1.4	1.6	1.2	24.0	33.6	38.4	28.8	660.0

were between 1.0 and 1.6 mg C /m^3/hr with the highest values being recorded at 10 m and the lowest value at the surface. The highest mg C /m^2/day (6,001.1) was observed in August and the lowest 746.0 mg C/m^2/day was in September over the upwelling period.

(xviii) Discussion

Chlorophyll a concentration, number of phytoplankton cells and C^{14} fixation rates are known to be indicators of the production rates of water bodies. Various workers have used one or a combination of two of these parameters or even all three to determine the productivity of an area. Graham (1943) states that a measure of the chlorophyll content of water is a measure of the photosynthetic capacity of the water body. Tunzi and Iorcella (1974) also concluded that C^{14} assimilation rates are highly correlated with algal chlorophyll concentration. Therefore changes in the above named parameters should be expected to show some relation one to another.

There is some relationship between changes in chlorophyll a concentration and changes in the number of phytoplankton cells especially during the July to October 1974 period of low water temperature ($< 24^{o}C$) when the highest cell number and the greatest

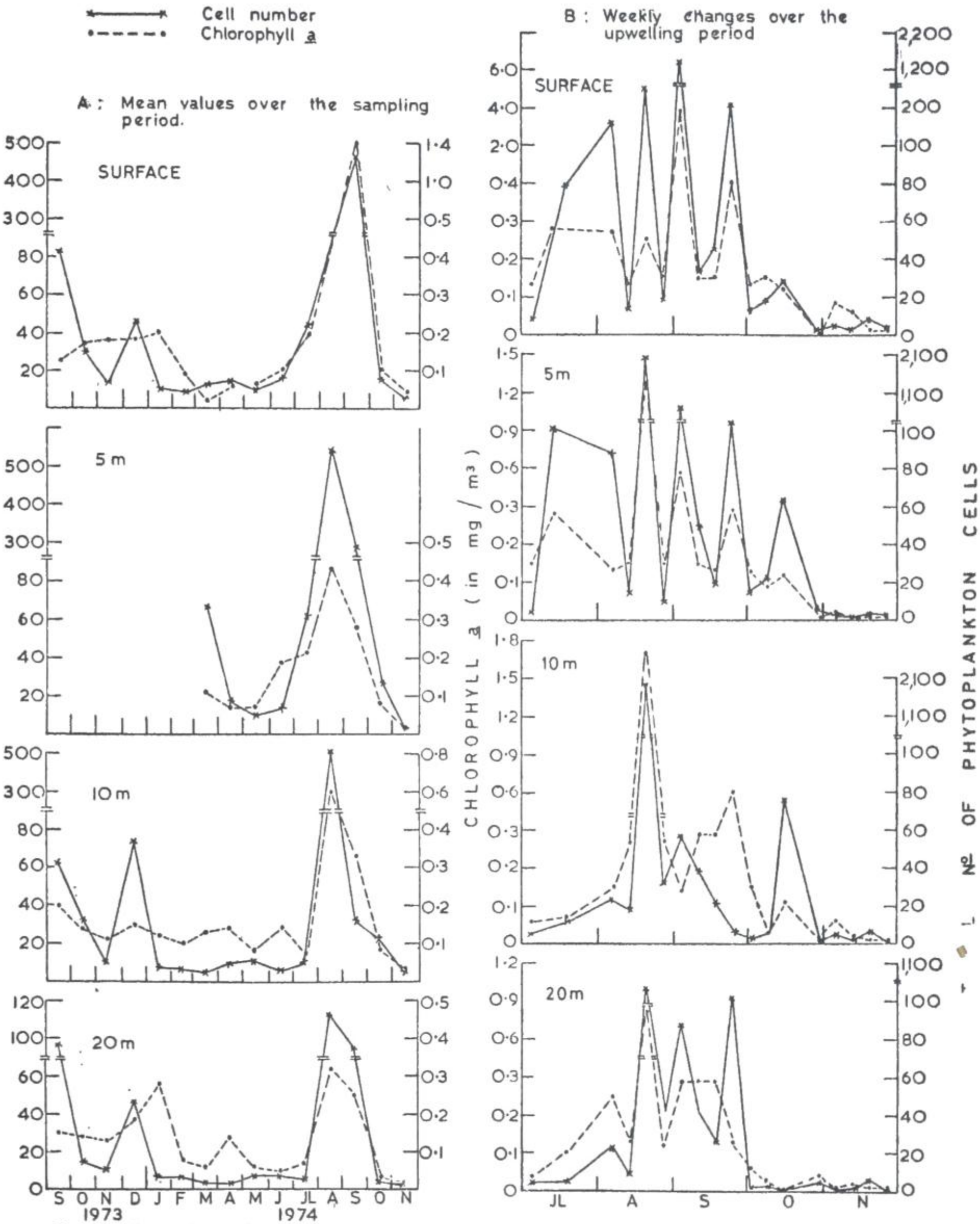

Fig. 16 – The relationship between changes in chlorophyll a and phytoplankton cell number at four depths at station A_1 off Tema.

chlorophyll a concentrations were recorded (Fig. 16a & b). For much of the rest of the study period both cell counts and chlorophyll a concentrations remained low. Nevertheless, when a dramatic increase in cell count took place in December 1973 there was no corresponding increase in chlorophyll concentration although a peak in chlorophyll a was measured about a month later in January when cell number were low at the surface and 20 m depth (Fig. 16a). Violent fluctuations in cell counts and chlorophyll a concentration occurred between July and October (Fig. 16b) and there was often a close relationship between them. At the surface the highest annual peak in cell counts on the 3rd of September clearly corresponded with the highest chlorophyll a peak. Although the major peak in cell count and chlorophyll a concentration were found on the same sampling occasion (3rd September 1974) there was not necessarily a correspondence between the heights of the peaks. For instance, the second peak in cell numbers (>664 x 10^3 cells/l) at the surface on the 20th of August corresponded with the fourth highest peak over this period in chlorophyll a concentration (0.25 mg Chl a/m^3). There was a close relation between the appearance of the peaks in cell numbers and chlorophyll a

concentration at the 5 m depth but again there was no correspondence in the relative heights, except on the 20th of August when the highest peak in phytoplankton cells correspondended with the highest peak in chlorophyll a concentration. At the 10 m and 20 m depths there was not always a close relationship between the peaks of phytoplankton cell numbers and chlorophyll a concentration with some peaks in cell numbers having no complementary peaks in chlorophyll a concentration. The best relationship between the two parameters for these two depths was found on the 20th of August when the highest phytoplankton cell count corresponded with the highest chlorophyll a concentration. At 20 m a high value for cell numbers (140 x 10^3 cells/l) was found on the 24th of September but no corresponding high level of chlorophyll a was measured. These discrepancies may in part, be explained by the fact that different genera formed the dominant components of the cell population at different times. For instance, in May, dinoflagellates such as species of Peridinium and Ceratium were dominant at the 10 m depth and these are known to contain about half as much chlrophyll as diatoms on cell volume basis (Gillbricht 1952, Williams & Robinson 1973) as compared with June when both species of Ceratium, Peridinium as well as diatoms such as

species of Coscinodiscus, Rhizosolenia, and Chactoceros were co-dominant. In July the chlorophyll a concentration was low possibly because about 80% of the cell population was made up of Nitzschia sp. which is known to contain low levels of chlorophyll per cell (Graham 1943). It seems likely that the concentration of chlorophyll might also be influenced to some extent by the amount of algal detritus in the water column, this detritus might come from benthic algae since station A1 is only 8 kilometers from the rocky coast. Gillbricht (1952) said that in some circumstances much of the measured chlorophyll might not have come from living algae but dead cells or even animal faeces. An attempt was made to count only the cells stained by the Lugol's solution, nevertheless it was not possible to distinguish between healthy and dying cells. Therefore it is possible that if a population contains a large number of moribund algal cells then a low chlorophyll a concentration will be measured as compared to one in which most cells are living and actively dividing. Between August and October the chlorophyll a concentration closely followed the changes in cell population possibly because at this time

the environmental conditions were particularly favourable for the phytoplankton population which was undergoing active growth. Thus it would seem probable that even within a single species, the chlorophyll content would vary depending upon the physiological condition of the cells.

Zeitschel (1969) measured chlorophyll a concentration off Fema between September 1963 and June 1964 and obtained values between 0.1-0.5 mg Chl a/m^3. The values for the present study went up as high as 1.7 mg Chl a/m^3 in August excluding the rather high value (> 4 mg Chl a/m^3) obtained during the red tide. The difference is probably due to the fact that Zeitschel's measurement did not cover the month of August when phytoplankton growth was at its peak.

The highest value for chlorophyll a concentration was recorded on the 3rd of September at the surface (Table 2) and this was the time when the red-tide caused by a high concentration of Mesodinium rubrum (90% of the phytoplankton population) was observed. If the red water ciliate is excluded from the results then vertical distribution shows that although the highest average number of phytoplankton cells was recorded at the 5 m depth the highest average Chlorophyll a concentration was recorded at the 10 m depth during the

TABLE 2 :

Peaks in Cell Counts and Chlorophyll a Values

	Surface		5m		10m		20m	
te	Cell Count /L	Chlorophyll g (mg/m^3)	Cell Count /L	Chlorophyll g (mg/m^3)	Cell Count /L	Chlorophyll a mg/L^3	Cell Count /L	Chlorophyll g (mg/L^3)
h August	158	0.271	89	0.145	23	0.145	23	0.247
h August	664	0.253	2,039	1.290	1,911	1. 72	374	0.797
d Sept;	1,466	4.926	700	0.578	57	0.143	88	0. 29
h Sept;	289	0.403	279	0.288	-	-	140	0.126
st Oct ;	28	0.116	63	0.116	76	0.116	-	-

upwelling period (Fig.17). Similarly Dandonneau (1972b) found that the depth with the highest number of cells lies above the depth with the highest chlorophyll concentration in the neighbouring Ivory Coast. Comparison between chlorophyll a values for the surface and the 20 m depth shows that although the surface has about twice the number of cells as the 20 m depth their average chlorophyll a concentrations are the same. These observations can be explained by the fact that cells at greater depths received less light than the ones nearer the surface therefore they contain more chlorophyll in order to be able to function properly. Steele (1964) concluded that mid-water chlorophyll maxima may be due to an increase in chlorophyll content of the plants rather than due to accumulation of plants due to sinking. Therefore the results of the present work agree with the findings of other workers.

Net primary productivity rates measured between July and November showed uniform changes along the water column (see Table 1). The highest value for all the depths (17.3 mg C /m^3/hr) was observed at the 20 m depth on the 23rd of August, a few days after the highest values for phytoplankton cell count and chlorophyll a concentration

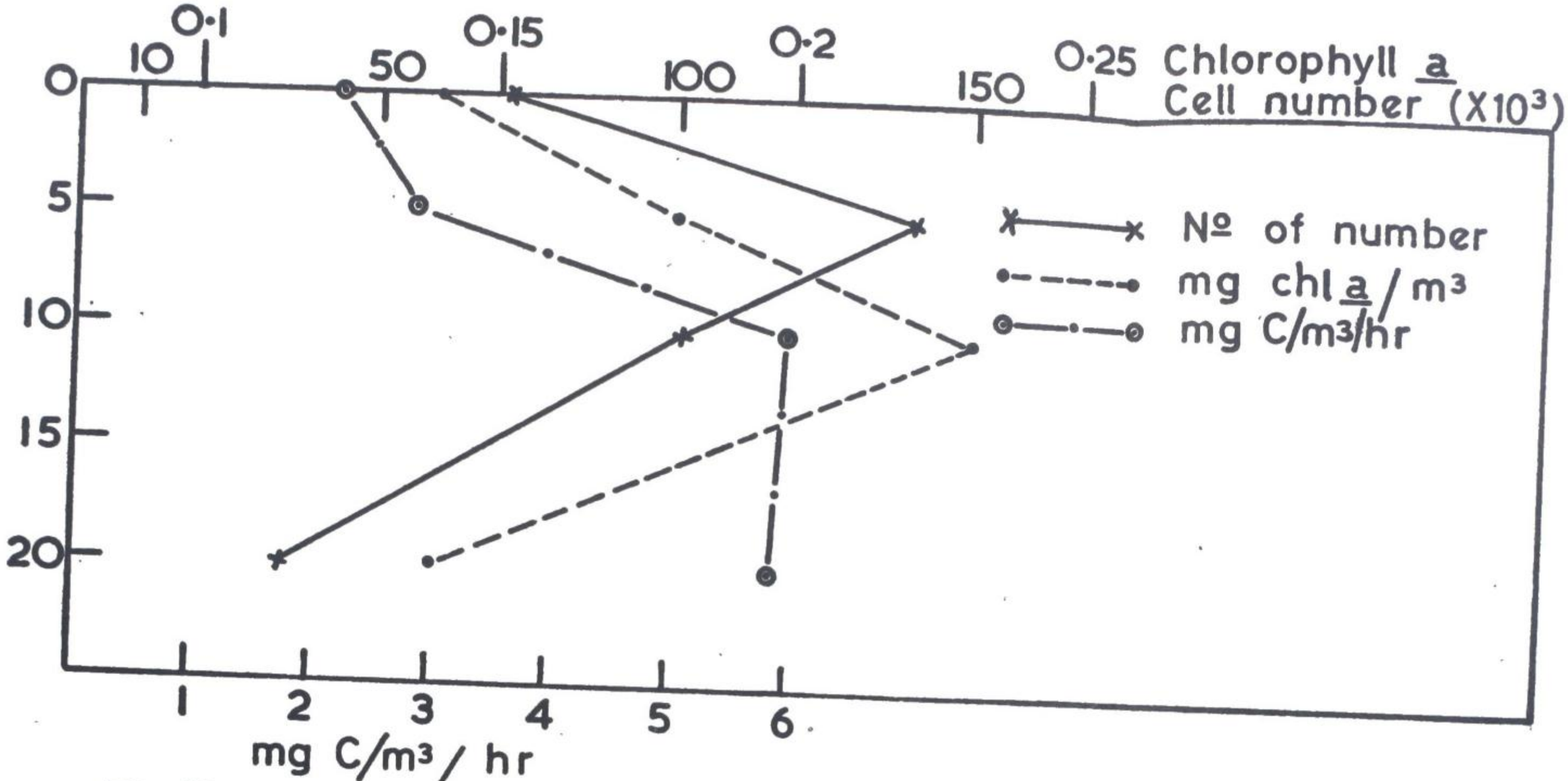

Fig. 17 — Vertical distribution of average cell number, chlorophyll a and net primary productivity rate at four depths at station A1 off Tema

were recorded at all depths except the surface (Fig.18). The second highest primary productivity rate was at the 10 m depth. In fact the difference between these two depths is very small (2 mg C/m^3/hr) as compared to the difference (> 12 mg C/m^3/hr) between the values for the 20 m depth and the surface and 5 m. At the surface the highest primary productivity value did not coincide with the highest values for phytoplankton cell count and chlorophyll a concentration because the red-tide that caused the peaks had disappeared at the time that the productivity studies were carried out in September. The highest average net primary productivity rate (5.95 mg C/ m^3/hr) was observed at the 10 m depth (Fig. 17). Again this value was very close to the value for the 20 m depth which was 5.85 mg C/m^3/hr. Nellen (1969) found that the highest primary productivity rate was obtained at the 25% and 10% incident of radiation which corresponded with 10 m and 16 m depths respectively off Tema and the highest average production rate was at the 10 m depth. Therefore the highest primary productivity rate occurs at greater depths (10 - 20 m). The highest net primary productivity value at the 10 m depth again coincided with the highest average chlorophyll a value which was observed at 10 m depth in the present study. Nellen (1969) also found that the depth with the highest

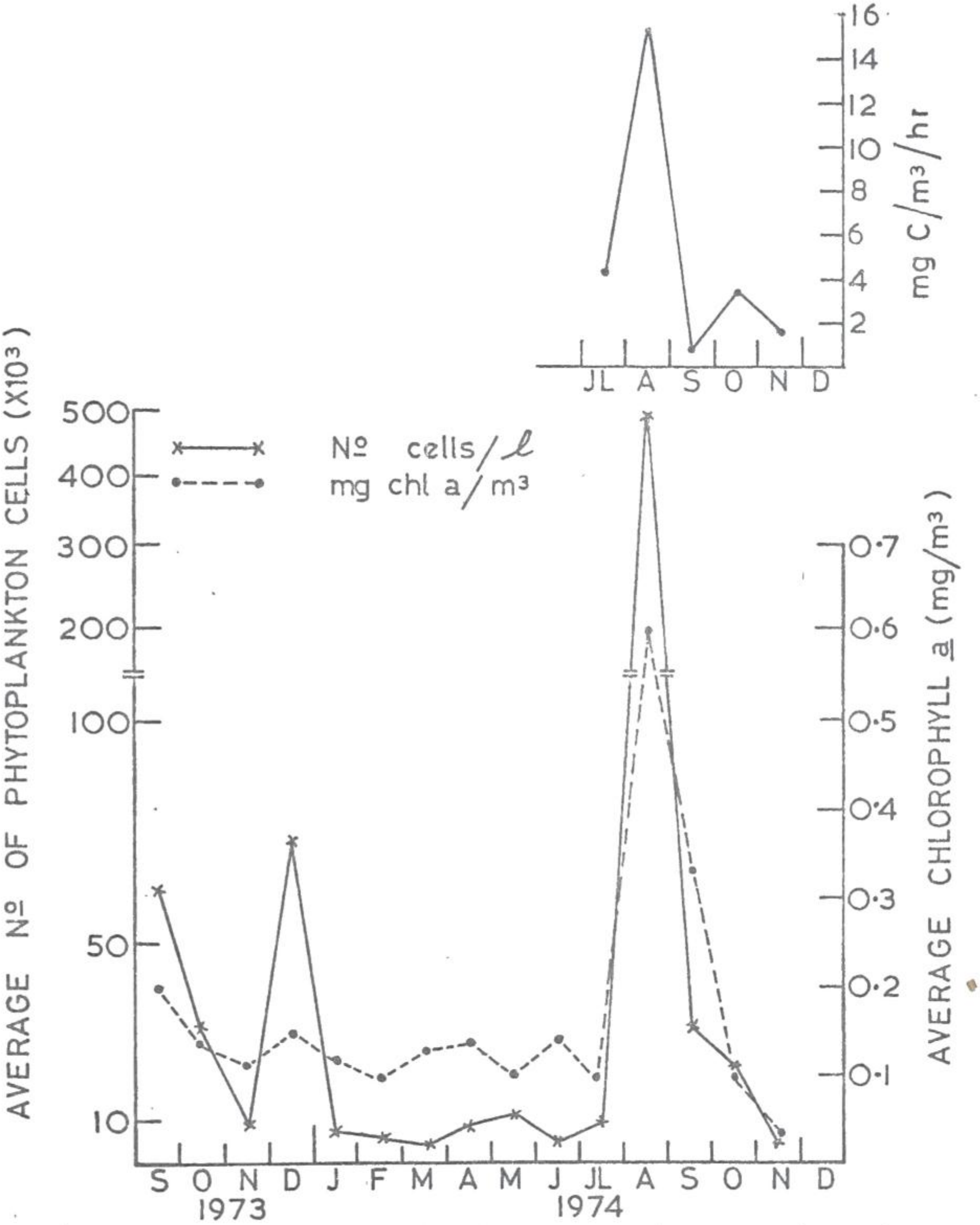

Fig 18 – The relationship between changes in phyto–plankton cell number, chlorophyll a and primary productivity rate.

productivity rate coincided with the depth with the highest chlorophyll a concentration. Ryther (1956) has observed that the rate of photosynthesis per unit of chlorophyll a remained relatively constant. Tunzi and Porcella (1974) have also found a high correlation between C^{14} assimilation and algal chlorophyll concentration. Therefore the present findings confirm the observations made by other workers.

Previous workers such as Bessonov & Fedosov (1965) observed that in October which is the last month of the upwelling period, daily primary productivity rate varied at various areas witin the waters off the Ghanaian coast. 70 miles to the west of Cape Three Points the highest rate was 3,800 mg C/m^2/day. In the Takoradi area primary production varied between 300 mg C/m^2/ day outside the upwelling period in May and 2,600 mg C/m^2/day during the upwelling period. Mahnken (1969), obtained values of more than 1,000 mg C/m^2/day for Cape Three Points. Nellen (1969) carried out primary productivity studies off Tema between February and May 1964, which was outside the upwelling period, and obtained an average value of 677 mg C/m^2/day. Therefore the observation that the average primary production rate was

600 mg C/m^2/day for November (non-upwelling period) and 2,358 mg C/m^2/day for the upwelling period (see Table I) in the present study compares favourably with the findings of previous workers. Reyssac (1969, 1970) obtained lower values of 296 mg C/m^2/day for the non-upwelling period and 985 mg C/m^2/day for the major upwelling period for the Ivory Coast. Dandonneau (1972b) obtained higher values (386-1,116 mg C/m^2/day) for the Ivory Coast. The minor differences in the results obtained for the two countries may be due to the differences in the time that the primary productivity rates were carried out since the duration of the phytoplankton bloom period can be a matter of hours or days (Loftus et al. 1972) The active growth period could easily be missed. Moreover even different points within the same area can have different primary productivity rates as shown by Bessonov and Fedosov (1965).

IV GENERAL DISCUSSION

It is well documented that qualitative and quantitative changes in phytoplankton populations are affected by a variety of factors such as temperature, nutrients, light conditions, grazing and rates of sinking. There is a complex interaction of these factors one with another to modify the effect a factor can have on the population. Loftus et al. (1972) state that phytoplankton organisms have a short

generation time (hours or days) and low motility, therefore their growth and physiological state might strongly be coupled to the physiological and chemical parameters of their environment.

This present study has shown that between July and October when the temperature of the Ghanaian off-shore water is low (< 24°C) and the salinity is high (> 35‰), then the highest yearly chlorophyll a concentration and counts of phytoplankton cells were observed (Fig.19). This period is also the time of the year when many of the nutrients known to be necessary for the growth of phytoplankton organisms are often in high concentrations. This large increase in nutrient concentration, fall in sea water temperature and rise in salinity measured from the surface to the 20 m was believed to be the result of the annual local upwelling off Ghana. (Ingham 1970, Longhurst 1964) There was also a minor upwelling in December 1973 which is shown by the decrease in temperature, small increase in salinity and increase in nutrient concentration at this time and consequently an increase in counts of phytoplankton organisms. This confirms the findings of other workers who found that a rise in productivity of the phytoplankton takes place in the Gulf of Guinea at this time of the year as a consequence of upwelling (Reyssac 1970, Dandonneau 1971, 1972 a & b).

Diatoms and dinoflagellates were found to be the two dominant groups of the phytoplankton organisms at station A1 off the Ghanaian coast. The dinoflagellates

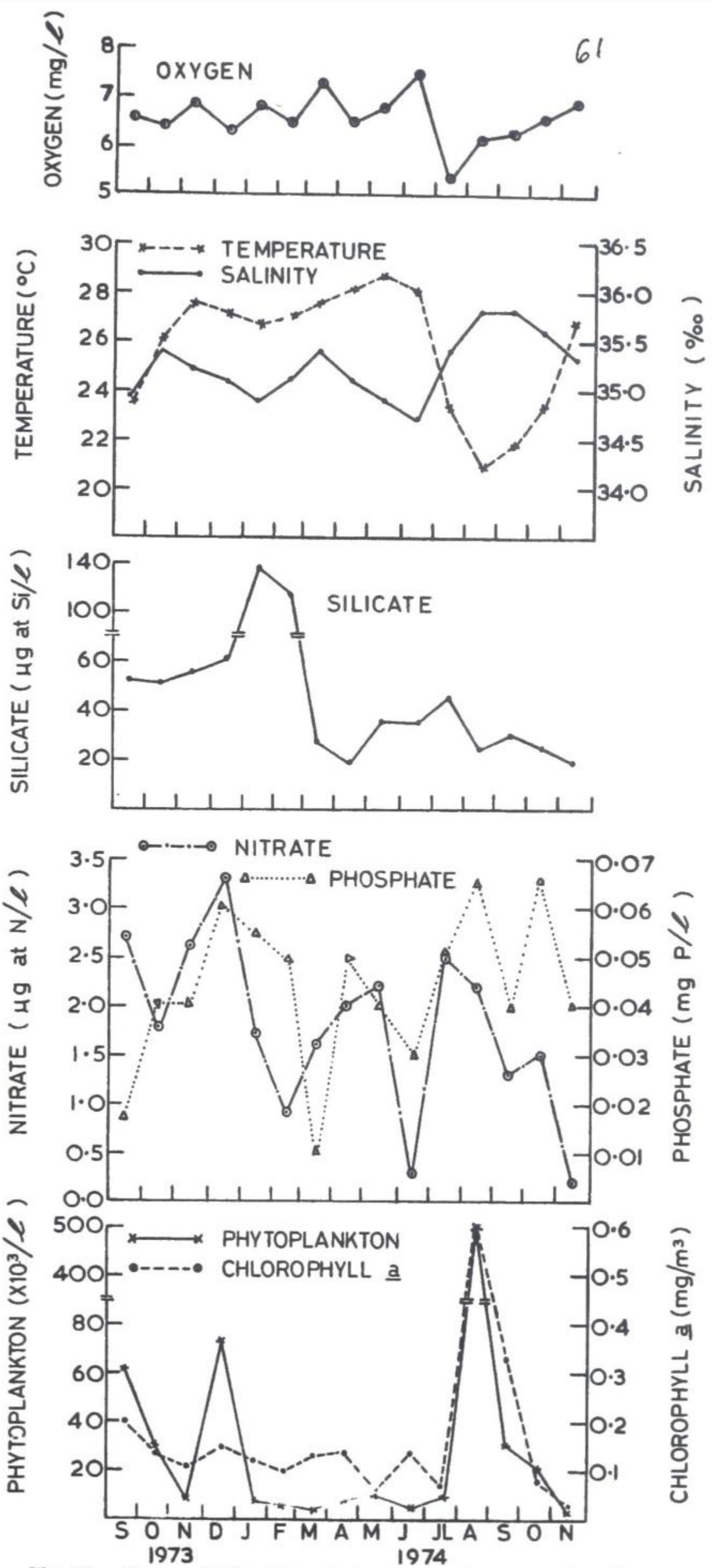

Fig. 19 – The relationship between changes in the physico-chemical factors, chlorophyll a and phytoplankton cell count at one depth at station A_1 off Tema.

almost disappeared completely during the major upwelling period so that diatoms often formed over 90% of the total cell numbers (see fig.13). The principal genera of diatoms present over the upwelling season in 1971 were species of Skeletonema, Nitzschia and Thalassiosira (see appendix 1). Reyssac (1966b, 1966c, 1970) and Dandonneau (1971) have similary observed that the high cell counts found during the upwelling period in the Ivory Coast was caused largely by diatoms but different genera to those found in the present study. Reyssac(1970) found a diatom bloom during the upwelling of colder mutrient rich water further north-wards along the West African coast in the shallow Baie du Levrier off Mauritania; the diatoms formed more than 90% of the phytoplankton organisms. Reyssac (1972) has also found that the main group of organisms that formed the bloom found off Angolan coast during the upwelling were diatoms. Outside the upwelling period when temperatures were high (24°C) and nutrient concentrations were generally low, dinoflagellates were the common components of the phytoplankton. Mulford & Norcross (1971) found that Ceratium sp was dominant during the warmer months in the Virginian coastal waters. Reyssac (1971) found that Gymnodinium sp prefers higher temperatures in Mauritanian waters. She also found that Dinophysis sp. and Peridinium sp. formed the main components of the phytoplankton in the waters off the coast of Angola during the warmer months(Reyssac 1972).

Reyssac(1966b, 1966c, 1970) found that flagellates were the dominant group during the non-upwelling season in the neighbouring Ivory Coast where conditions are similar to those of Ghana. The observations of the present study therefore confirm the findings of other workers that dinoflagellates are often abundant at higher temperature.

Dinoflagellates are able to grow successfully in waters of relatively low nutrient concentrations. For example Ceratium sp. have slow growth rate and low nutrient requirements therefore they continue to grow in impoverished waters (Sverdrup et al. 1942). Wilson (1965) observed that dinoflagellates are able to grow in waters of relatively low phosphorus concentration. Moreover high dinoflagellate populations are observed to succeed diatom blooms when the nutrient level is low due to uptake by the diatoms(Ryther 1955). Barker(1935) observed that Prorocentrum micans can tolerate a wide range of nutrient concentration. These observations suggest that dinoflagellates can thrive in nutrient poor waters and may account for their abundance at the time of the year when water temperatures are high (>25 ^{o}C) and nutrient concentrations are low in the Gulf of Guinea.

Cell counts and nutrient concentrations were high during the upwelling period, nevertheless violent fluctuations occurred in both. There was found to be a good correspondence between increase in phytoplankton cell counts

and decrease in nutrient concentration (Fig.20), resulting from the utilization of the nutrients by the phytoplankton organisms. The decline in silicate, phosphate and nitrate concentration as a result of uptake by phytoplankton organisms was particulary pronounced on the 20th of August when the phytoplankton bloom was at its peak. Such a relationship between cell numbers and nutrients was shown by the decrease in phosphate and nitrate concentrations on the 3rd of September 1974 when a large population of the red tide ciliate Mesodinium rubrum, which is known to be a functional autotroph, was observed. Laboratory and field studies have shown that nutrients such as silicate, nitrate ammonia, amino acids and phosphate are readily taken up by algal cells. For example, the uptake of silicate has been shown by Jørgensen(1952, 1953), nitrate uptake has been shown by Provasoli(1958), Bienfang (1975), Eppley et al.(1969), Eppley & Coatsworth(1968), Grant et al.(1967), Strickland et al.(1969), and Syrret & Morris(1963), among others. Ammonia uptake has been shown by Eppley et al.(1969), and Wheeler et al.(1974). Malone et al.(1975) and Thomas (1970) state that growth of marine phytoplankton is often limited by the availability of dissolved inorganic nitrogen. Uptake of phosphate has been shown for both diatoms and dinoflagellates. For instance many workers such as Wilson(1965), Ketchum(1939), Kain & Fogg(1958 a,&b) and Provasoli & Pintner(1953) considered phosphorus as one of the natural limiting factors

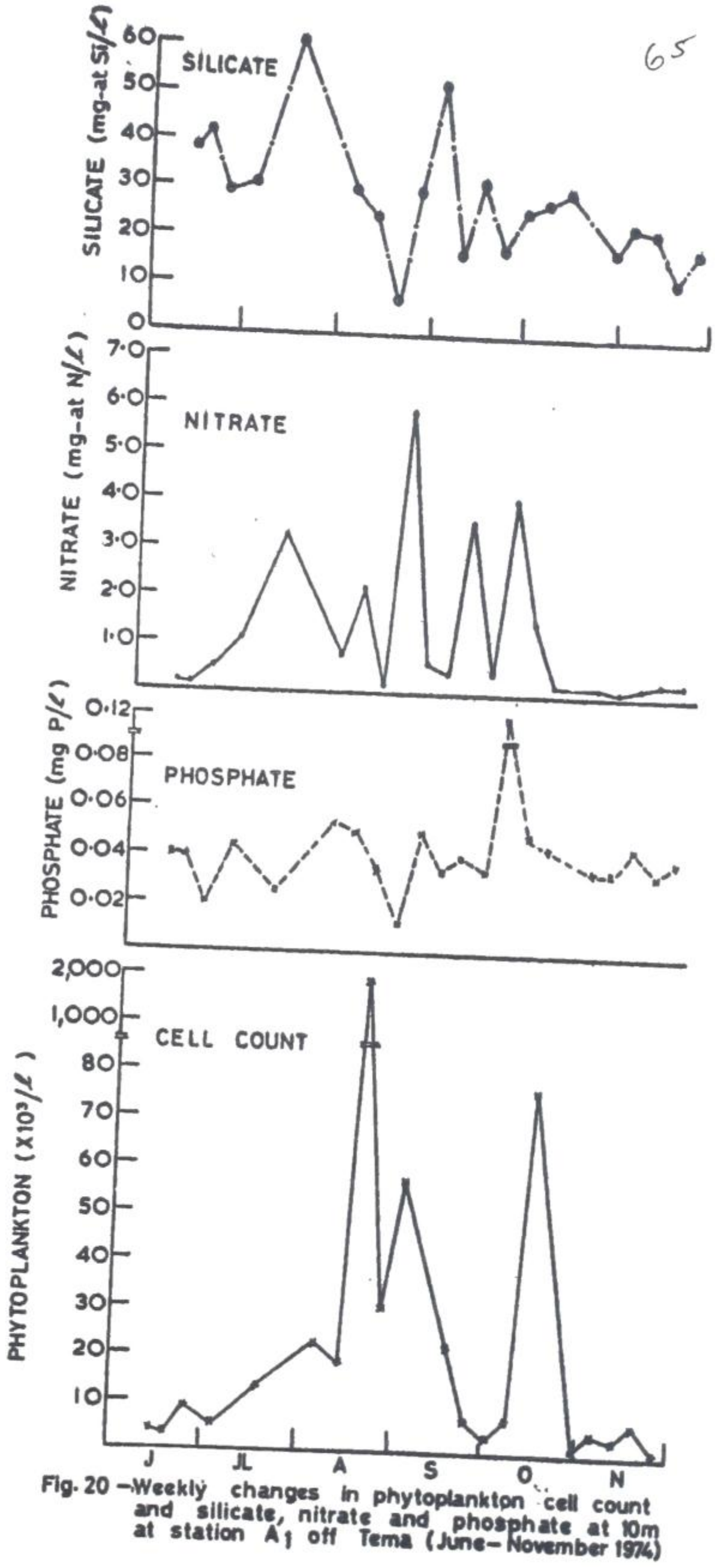

Fig. 20 —Weekly changes in phytoplankton cell count and silicate, nitrate and phosphate at 10m at station A_1 off Tema (June–November 1974)

for the growth of algae. Diatoms require silicate for the formation of their frustules and lack of it prevents the frustules from attaining sufficient size for the next cell division. Uptake of silicate by Nitzschia palea in freshwater and Bacillaria paradoxa in salt water has been clearly shown by Jørgensen(1952, 1953). He found that the growth rate decreased when concentration of silicate was low even in the presence of other nutrients. Therefore silica is one of the limiting factors for the growth of diatom populations and the large fluctuations found in the upwelling period reflect the consecutive increases and decreases in diatom cell numbers. The very large increase in silicate recorded in January and February was not accompanied by a diatom bloom possibly because of the frequent break-down of the research vessel in those months and it is possible that any bloom that might have developed had been missed. Reyssac (1970) found a small diatom bloom between January and February at the time of the local minor upwelling season in the Ivory Coast.

There is a close correspondence between the sudden decline in the cell number of the phytoplankton population and the appearance of high concentrations of the various nutrients such as phosphate, nitrate and silicate. This could be accounted for by the rapid release of the nutrients on the death of the phytoplankton organisms or, as suggested by Steele(1958) and Martin(1965, 1968) by their ingestion and excretion by zooplankton.

The physico-chemical results show that there is no development of a distinct thermocline and it seems that the water column at least down to 20m, is well mixed. Therefore nutrients are not lost to lower levels and even nutrients such as silicate rapidly reappear on the break-down of the phytoplankton organisms. The appearance of the red-tide on the 3rd of September poses a problem as to the origin of the high concentration of nutrients measured on the 27th of August. One possibility is the horizontal water movement into the vicinity of the sampling station. In fact only a very weak current was measured at station A, between 15 and 30 m just before the appearance of the red-tide on the 3rd of September. Also on the 30th of August a rather calm sea(wind speed ½ knot) was observed at 09.00hrs. at station A1. The origin of the red-tide is difficult to say but conditions prevailing at this time agreed with those normally observed for such blooms.

Iverson et al.(1974) concluded that water column stabilization is a prerequisite to the development of the spring phytoplankton bloom. A similar conclusion has been drawn from observations made by Gran & Braarud (1935), Riley (1942), Sverdrup(1953) and Taylor et al.(1971) that a stable water column together with high phosphate concentration are prime factors causing blooms of the ciliate Mesodinium rubrum. The observation made in the present study confirms the findings of other workers.

It seems that the stable water column together with the high concentration of nutrients observed on the 27th of August possibly released by the breakdown of the previous bloom of phytoplankton organisms are the possible factors that brought about the bloom of the red-tide organism observed at station A 1 off the Ghanaian coast.

Changes in dissolved oxygen concentrations in water bodies have been used as indications of fluctuations in the rate of primary production. There was some correspondence between phytoplankton cell numbers and dissolved oxygen levels in the present study but this was not invariably the case. For instance, the peak in cell number found on the 15th of October was not accompanied by a corresponding increase in oxygen concentration. Nevertheless, the high oxygen values (> 8 mg/l) observed at the surface, 5 m and 10 m on the 20th of August corresponded with the peak of phytoplankton production (Fig.21). Biswas (1966) also found that increase in algal cell concentration corresponded with increase in dissolved oxygen in the Volta Lake in Ghana. Reyssac (1970) similarly found the highest oxygen concentration to be in August at the 25 m-deep station off the Ivory Coast but again she did not always find a relationship between the phytoplankton cell numbers and dissolved oxygen concentration. The high level of photosynthetic activity

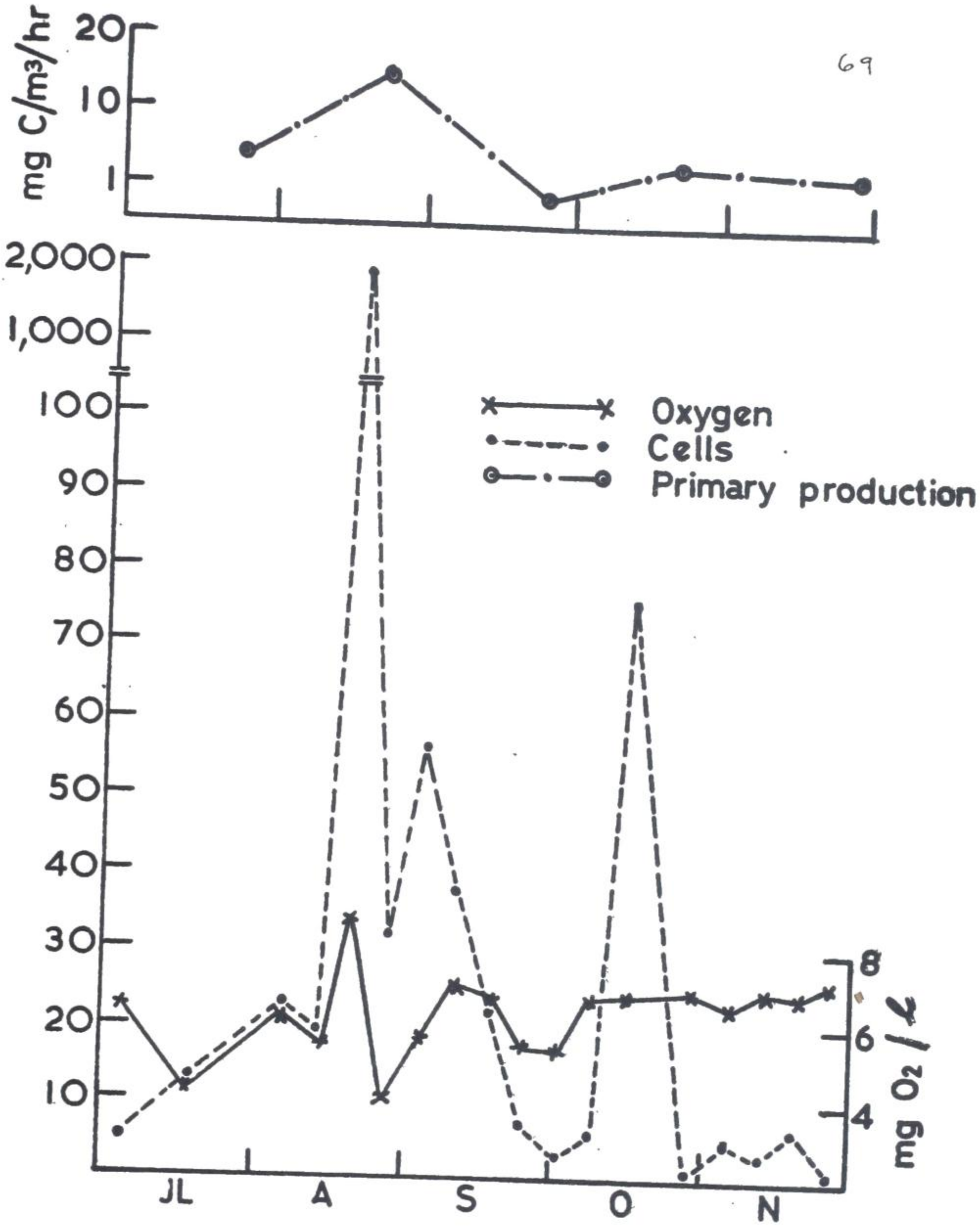

Fig. 21 - Changes in oxygen concentration, primary production rate and phytoplankton population at 10 m at station A_1 off Tema Ghana.
(July – November 1974)

would account for the rise in dissolved oxygen content of the water when a relation appears to exist. The rapid fall in oxygen content on the 27th of August may be due to rapid uptake by bacteria acting on the decomposing dead cells. Zooplankton respiration may also be an important factor in bringing about this drop since the number of such organisms most probably increased at the time of the phytoplankton bloom.

Apart from the effect of physico-chemical factors, on the phytoplankton population, grazing by herbivores also caused some changes in the phytoplankton population. Zooplankters are known to be the main herbivores therefore the rapid decline in phytoplankton cell numbers at short intervals between July and September might be due to grazing by zooplankton organisms in the present study. Copepods are reported to be one of the principal grazers of diatoms(see Lebour 1922, Marshall 1924, Sverdrup 1942, among others), although they also feed on dinoflagellates and coccolithophores(Esterly 1916, Marshall 1924). During the time of the principal upwelling in Ghana copepods form the main components of the high zooplankton population(Mensah 1969), therefore the sudden decreases in the phytoplankton population over this period might be due to grazing by copepods. Mensah(1972) has found such diatom genera as Thalassiosira and Skeletonema in the gut of the copepod Calanoides carinatus during the upwelling period

in Ghanaian waters, Marshall (1924) found such genera as Skeletonema and Thalassiosira in the gut of the copepods she examined whilst Martin (1970) has found that Skeletonema sp was selectively grazed. In contrast Iverson et al. (1974) did not find any Skeletonema costatuma in the feacal pellets of the copepods examined despite the fact that it formed the most abundant species in the phytoplankton. This implies that in this case the copepods were not grazing the Skeletonema costatum. Other copepods such as Acartia tonsa and Pseudocalanus minutus are known to graze Skeletonema costatum (Curl & Mcleod 1961, Parsons & Le-Brasseur 1966, Martin 1970). They explained the absence of Skeletonema costatum frustules in the feacal pellets of copepods by the fact that the frustules are particularly delicate and may have been destroyed during digestion. The findings by Marshall (1924) and Mensah (1972) of Skeletonema frustules in the gut of copepods might be due to the cells having not undergone complete digestion at the time of analysis. In conclusion, the rapid disappearance of such diatoms as Thalassiosira, Skeletonema and Nitzschia, often the main components of phytoplankton bloom, could be partly due to grazing by the zooplankton organisms.

The greatest numbers of phytoplankton cells were not usually found at the water surface but some meters below

(see Fig.17). In the present study sampling was done at 09.00hrs. and the greatest concentration of phytoplankton cells were found at the 5 m depth and below. An exception to this pattern was observed on the 3rd of September 1971 during the time of the red-tide. Cell count was highest at the surface on that day and 98% of the population was made up of the ciliate Mesodinium rubrum which contained chlorophyll within functional chloroplasts usually regarded as incomplete endosymbionts. This organism can therefore be regarded as a functional autotroph. The ciliate cells were almost 1,500/ml at the surface whilst at 10m and below they dropped below 100/ml (Fig.22). The chlorophyll a value was highest (4.9mg chl a/m^3) at the surface and fell below 0.5mg chl a/m^3 at the 10 m and 20 m depths. The total cell count shows a similar decline with depth but below 10 m an increase in number occurred due to the high concentration of diatom cells at 20 m. These findings are in agreement with those found by other workers (see Taylor et al. 1971 for references) that during the day and under cloudless conditions, the highest numbers of ciliate cells are near the surface and decrease with increasing depth. Unlike many phytoplankton organisms this ciliate has well developed powers of locomotion and as Bary and Stuckey (1950) have observed it exhibits a strong positively phototactic response.

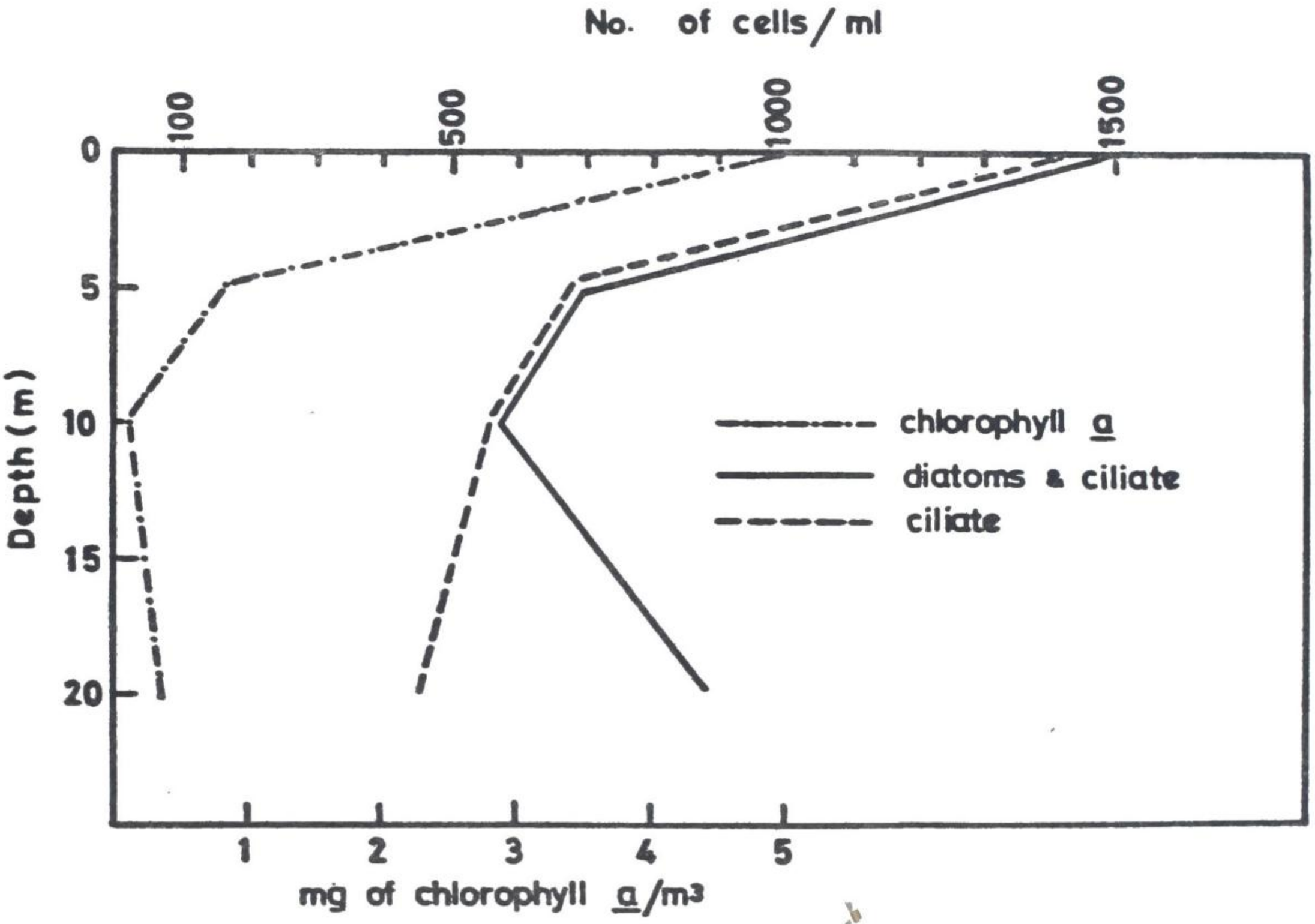

Fig. 22 — Vertical distribution of chlorophyll a and the ciliate Mesodinium rubrum on 3rd Sept. 1974.

The stable water column conditions and high phosphate concentration observed just prior to the appearance of the red-tide are the possible cause of the Mesodinium bloom (see Taylor et al. 1971).

In conclusion, it appears that there are two main marine seasons found in Ghanaian waters. One of these corresponds to the rainy season when there is a major upwelling of colder, more saline and nutrient-rich water (July - October) whilst the other season is characterised by higher water temperatures, lower salinity and lower levels of nutrients. This latter marine season is broken by a weak and limited upwelling which occurs usually between December and January. A consequence of the upwelling is to bring about a dramatic increase in primary productivity which in turn must profoundly affect higher trophic levels and hence the whole Ghanaian fishery. It is well established fact that poor fish catches along the Ghanaian coast always correspond to years in which there was a very weak upwelling.

V.

S U M M A R Y

1. Ghana, which has a sub-equatorial climate, experiences major and minor upwellings in July-October and December respectively. During the major upwelling period surface water temperatures are lowest (< 25°C), salinity is highest (>35°/00) and nutrient concentrations are high. The minor upwelling in December is also characterised by a slight decrease in temperature, increase in salinity and nutrient concentration. At other times of the year temperatures are high (>25°C) salinity is low (<35°/00) and nutrient concentrations are low.

2. Phytoplankton cell counts and chlorophyll a concentration show seasonal changes with the highest values (>1.0 mg chla/m^3 and >1000 x 10^3 cells/l) being observed over the major upwelling period. A small increase in these measures occurs also in December.

3. The composition of the phytoplankton shows flagellates almost completely disappearing during the principal upwelling. Diatoms are dominant over much of the year and form over 90% of the cell counts for much of the period of upwelling. On the 3rd of September the ciliate Mesodinium rubrum was dominant.

4. Large fluctuations occur in cell numbers and the concentration of nitrate, silicate and phosphate particularly over the period of major upwelling. There

is a good correspondence between the peaks in phytoplankton numbers and low levels of nutrients, with the converse taking place at other times. The release of these nutrients takes place rapidly on the disappearance of the phytoplankton bloom with nutrients not being lost to lower levels at the shallow station sampled.

5. The levels of dissolved oxygen and phytoplankton cell concentration only occasionally show a close correspondence. The highest oxygen concentration (> 8 mg/l) was measured at the time of the highest peak in cell numbers which is over the period of the major upwelling.

6. Vertical distribution of phytoplankton cells shows that the highest number of cells are usually at the 5 m depth or below. Mesodinium rubrum had its highest cell numbers at the surface on the 3rd of September 1974.

7. Primary productivity rates also show seasonal changes with the highest average seasonal value (2,358 mg C/ m^2/day) being observed during the upwelling period and the lowest value (660.0 mg C/m^2/day) being observed in November outside the upwelling period. The values obtained are comparatively higher than those usually observed for tropical regions.

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	1973								1974						
	Sept	Oct	Nov	Dec	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov.
(I) DIATOMS a. Skeletonema sp.	+ + +	+	+	+ + +	+	-	-	-	+		+	+ + +	+ + +	+ + +	+
b. Nitzschia sp.	+ + +	+	+	+ + +	+	-	-	-	+	+	+ +	+ + +	+ + +	+ + +	+
c. Thalassiosira sp.	+ + +	+	+	+	-	-	-	-	-	-	+	+ + +	+ + +	-	+
d. Coscinodiscus sp.	-	-	-	+		-	-	-	+	+		+	+	+	-
e. Chaetoceros sp.	-	-	-	-	-	-	-	-	+	+	+	-	-		-
II. DINOFLAGELLATES															
Peridinium sp.	+	+ + +	+ + +	-	+	+ + +	+ + +	+	+ + +	+	+	+	+	+	+ + +
Prorocentrum sp.	-	+	+	+	+	-	+	+	+	+	+	+	+	+	+
Ceratium sp.	+	+ + +	+ + +		+	+ + +	+ + +	+ + +	+ + +	+	+	+	+	+	+ + +
Dinophysis sp.	+	-	+		+	+	+	+	+	+	+	+	+	+	+

+ + + = Colominand, + + = Dominant, + = Present, - = Absent