

STUDIES ON THE PRIMARY PRODUCTION IN THE INDIAN SEAS

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This is to certify that this Thesis
is an authentic record of the work carried out
by me at the Central Marine Fisheries Research
Institute and that no part thereof has been
presented before for any other degree in any
University.

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P R E F A C E

The measurement of the photosynthetic fixation of carbon by the plankton algae in the aquatic environment has been an important investigation extensively undertaken in many parts of the world during the last two decades. Though technically it is possible to estimate the productivity by several methods, the oxygen and radioactive carbon techniques have been mainly used for collecting field data both from fresh and marine waters. The candidate has been engaged in studies on primary production since 1957, when the Central Marine Fisheries Research Institute, with which he is associated, initiated a programme of research at Mandapem on the south-east coast of India.

A planned programme of research for over four years conducted in the inshore waters of Mandapem showed that this region has a remarkably high rate of production during a greater part of the year which sustains a rich and variegated fauna including luxuriant coral reefs and fishes. Values comparable to the highest rates of primary production measured anywhere in the marine environment were recorded from some inshore stations during periods of high phytoplankton production.

A reliable standardization of stock solutions of ^{14}C and the counting equipment is an essential pre-requisite in order to get comparable and meaningful values in primary production measured by ^{14}C technique. During the spring of 1964 the candidate spent some time in Copenhagen with Prof. E.Stemann Nielsen at the Botanical Laboratory of the Danish Pharmaceutical Institute, where he got acquainted with the experimental methods and biological standardization of ^{14}C . Cultures of Chlorella brought by him from Copenhagen were developed at Mandapam for biological standardization of the stock solutions made in the country. In the course of a comparative study of the different methods of standardization, he obtained Millipore filters laden with thin layers of radioactive plastic, from Dr. H.R.Jitts of Commonwealth Scientific and Industrial Research Organisation, Australia. Standardisation and calibration were carried out with a windowless gas flow proportional counting system, developed by the Electronics Division of the Atomic Energy Establishment (now Bhabha Atomic Research Centre), Bombay and a liquid scintillation counter at the Radiochemistry Division of the Centre. The candidate obtained almost identical values with the biological and scintillation methods. Inter-

comparison of values obtained with the stock solution and counter at the Institute was made with those of the International Agency for ^{14}C Determination at Chabottenlund and C.S.I.R.O. Australia from parallel in situ experiments. These efforts helped him a long way in obtaining comparable and more accurate results in his studies.

From 1965 the candidate has been involved in productivity measurements along the west coast of India and the Laccadive Sea.

As the need for utilising the primary production data for estimating the living resources and the potential yield was felt, the candidate undertook a study of the primary production of the Indian Ocean, in general, for which some data collected by the participating ships in the International Indian Ocean Expedition were used. On the basis of this it was possible to make a quantitative assessment of the potential resources.

Short-term studies on some special types of ecosystems have also been made during the course of the candidate's work. After a devastating cyclone along the south-east coast of India in December 1964, several low-lying areas were inundated and were teeming with diverse organisms. It was a unique type of ecosystem with oceanic forms of phytoplankton temporarily occupying land-locked

pools with fast changing environmental conditions and succession patterns. Besides, productivity of the mud banks along the Kerala coast and the coral reefs in the south-east coast, Minicoy and Andaman Islands were also studied for short periods. The growth kinetics of the mixed populations of phytoplankton and some selected species under natural conditions and of a laboratory culture of a green flagellate, Tetraselmis gracilis Kylin, were also undertaken which form the first ever observations of similar nature from here. The study of the seasonal variation of the different phosphorus fractions in relation to primary production and total organic nitrogen of the particulate matter are also studied for the first time.

The studies conducted by the candidate during a greater part of the last seventeen years as a member of the staff of the Central Marine Fisheries Research Institute, have been oriented toward an assessment of the potential resources in the seas around the Indian Peninsula. These investigations were the pioneering ones from the Indian seas and from the time of initiation, efforts have been made to refine the technique and approach to the problem. These studies, have, in a large measure, added to the understanding of the primary productivity in the Indian seas.

The candidate is indebted to Dr.R.Raghun Prasad, new Assistant Director General, Indian Council of Agricultural Research, New Delhi, who put him on to these studies and for his guidance during the major part of the work and also for his continued interest and encouragement.

The successive Directors of the Institute, Dr. N.K. Panikkar, Dr.S.Jones, Dr.S.Z.Qasim and Dr. R.V.Nair extended all facilities and encouragement to the candidate in carrying out this work. The late Dr. V.K.Pillai, then Director, Central Institute of Fisheries Technology and Mr. S.K.Banerji, now in FAO, Rome, gave several suggestions in chemical oceanography work and in the estimation of potential resources. Prof. G.V. Kurien, Dean of Marine Science, Cochin University and Dr. E.G.Silas, Head of the Division of Marine Biology and Oceanography of this Institute gave constant help and encouragement in the preparation of the thesis. Messrs. K.J.Joseph, V.K.Balachandran and C.P.Gopinathan, his colleagues in the section extended their whole-hearted co-operation both in the field and in the laboratory. Dr. G.S.Sharma and Mr. D.S. Rao and several other colleagues in the Institute have been helpful with many suggestions.

Dr. H.R. Jitts (Australia) had given the radioactive Millipore filters for the standardisation of the counter and rendered valuable help in the work connected with it. The candidate wishes to thank each one of them.

The candidate expresses his immense gratitude to Prof. E. Steemann Nielsen, the doyen of primary production research, for the many courtesies and valuable suggestions received ever since the beginning of this work. His prompt response on every occasion has been a constant source of inspiration and guidance.

INTRODUCTION

All the earlier investigations concerning productivity of the Indian seas were based on the standing stock of phytoplankton taken with tow nets. Although considerable information was available on such standing crop measurements, no data were available on the production of organic matter per se, when these investigations were initiated in 1957 in the inshore waters of Mandapem, along the south-east coast of India.

The word production has been used synonymously with standing crop. But there is a sharp distinction between the two, though in nature there is rather a high correlation between the standing stock of phytoplankton and primary production. Primary production represents the quantum of organic matter produced by the planktonic algae and the benthic flora utilising the light energy from the sun and the nutrients in the environment. Since it initiates the whole marine food chain which terminates in the larger fishes and sea mammals, this study provides a useful basis for an assessment of the potential yield of fishery resources.

To begin with, the well-known light and dark bottle technique formed the basis for the measurements. Later with the availability of carbon-14 from the International

Agency for ^{14}C Determination, Charlottenlund, Denmark, data were collected from different regions in the Gulf of Mannar and Palk Bay along the south-east coast of India. A systematic study extending over a period of four years yielded very useful information on the production of organic matter and based on this an assessment of the potential resources in the inshore waters of the Gulf of Mannar was made. Gradually with the procurement of counting equipment and radio-isotope of carbon from the Atomic Energy Establishment, Trombay, Bombay, studies were extended to the south-west coast of India and the Laccadive Sea. During the International Indian Ocean Expedition a large amount of data was collected by the participating countries on primary production and the environmental phenomena that regulate it from different regions of the Indian Ocean, the results of which are being published. But data from the inshore and offshore regions of the Indian Peninsula are lacking. These studies, thus, form a major complement to the investigations on the primary production of the Indian Ocean from a vitally important sector, where there is much seasonal and geographical variability.

The results presented here in ten chapters are based on the candidate's work from 1957 along the south-east and south-west coasts of India and the Laccadive Sea.

Chapter I contains the introduction and historical résumé in which the development of methods of estimating primary production till the ^{14}C technique was introduced and the subsequent controversy have been briefly reviewed along with the work carried out in the Indian seas.

In chapter II on the environment, a short description of the areas along the south-east and south-west coasts of India, where the investigations were mainly carried out, has been given together with the hydrological conditions and the plankton characteristics of the area.

Chapter III, on materials and methods, contains details of the techniques employed. A critical appraisal of the methods of standardisation, intercalibration trials with different stock solutions of ^{14}C and a comparison of the results obtained by the two techniques have also been included in this chapter which form a necessary adjunct for a proper evaluation of the results.

Chapter IV deals with the seasonal and quantitative variations of the common phytoplankters and the general growth kinetics of the total population and some selected species. Growth trend and productivity characteristics of a green flagellate, Tetraselmis gracilis, in culture have also been presented in this chapter.

Chapter V gives the seasonal and regional variations in primary production in the different areas such as inshore and oceanic waters of the Indian seas. The daily rate of production and the magnitude of annual production in the Gulf of Mannar, Palk Bay, west coast of India, the Laccadive Sea and the mud bank south of Alleppey are dealt with and in addition, an account of the productivity of the Indian Ocean in general, is included based on available data.

Chapter VI deals with the factors influencing primary production. Section 1 deals with the measurements of light penetration and the depth of the euphotic zone in the different regions of the Indian seas. Section 2 contains the variations of the common nutrients such as phosphate, nitrate and silicate during the summer months preceding the monsoon, periods of south-west monsoon and post-monsoon months. Sections 3 and 4 deal with the relationships of the standing crop of phytoplankton as estimated by cell counts and chlorophyll, and of numerical abundance of zooplankters in a shallow area of the Gulf of Mannar.

Chapter VII deals with the different phosphorus fractions in relation to primary production in the Gulf of Mannar. Chapter VIII contains results of investigations on total organic nitrogen (converted into protein equivalent)

of the particulate matter studied in conjunction with primary production for over an year in the Gulf of Mannar.

Chapter IX contains a review of the primary productivity of world oceans to demonstrate the comparative rate of primary production in the Indian Ocean vis-a-vis the rest of the oceans. Chapter X contains the findings on potential resources of the Indian seas based on estimates from primary production measurements as well as results of exploratory fishery surveys. In fact, resources estimation has been a major objective of these investigations and the results obtained have been most encouraging.

Historical Resume'

Investigations on the production of organic matter in a coastal region were first made in the English Channel. By determining the changes in alkalinity (loss of CO_2) Atkins (1922) estimated the production of dextrose for a unit area. But the values were considered as minimal because the exchange of CO_2 with the atmosphere could not be taken into account. Subsequently Atkins (1923) calculated the annual plankton crop from phosphate consumption and arrived at figures identical with the earlier calculations, the agreement, though fortuitous, lending support to the validity of the alkalimetry method. This was followed

by Kreps and Verjbinshaya (1950) who calculated the production in the Barents Sea in terms of 'wet weight' of phytoplankton using Atkins' estimate that the phosphate content of the wet weight of phytoplankton is about 0.15% and arrived at production values in terms of glucose per unit area of surface. In the English Channel again Cooper (1933) calculated the annual phytoplankton production from phosphate consumption which was subsequently corrected to a higher figure on the basis of salt error corrections for phosphate (Cooper, 1938). Seiwell (1955) calculated the annual production of the surface waters in the tropical western North Atlantic based on a previous estimation of oxygen consumption in the vertical water column within the region of investigation. Riley and Gergy (1948) used the vertical distribution of oxygen in the Sargasso Sea to estimate production. By standard physical oceanographic methods the net oxygen production per day in the depth range between 25m and 100m was estimated which was then converted into its carbon equivalent. Harvey (1950) and Steele (1956) also used phosphate consumption to estimate production at the Plymouth Sea area and Fladen ground respectively. Ryther and Yentsch (1957) have used chlorophyll and light data to compute gross primary production. A review of the various aspects of primary production has

been given by Steemann Nielsen (1932, 1938^a, 1960, 1963 and 1964), Ryther (1956), Laevastu (1958), Steele (1961) Yentsch (1963) and very comprehensively by Strickland (1960, 1965) and Vollenweider (Ed.) (1969).

The first really direct method of estimating the production of organic matter using light and dark bottle was introduced by Pütter (1924) and subsequently by Gaaarder and Gran (1927). It had been found from earlier observations that there is often a distinctly demonstrable agreement between the occurrence and extent of the phytoplankton and the changes in the quantity of oxygen in the uppermost layers of water. Because the quantity of oxygen and carbon dioxide of the water are directly influenced by the metabolic processes of the plankton, it is assumed that production can be estimated through their changes. The photosynthesis of the plankton algae and their respiration act in opposite directions. But when photosynthesis predominates, the determinations of oxygen must be expected to give quite good minimum values for the photosynthesis of the plankton algae and thereby for the production of organic substance. This method was subsequently used by Marshall and Orr (1928, 1930) to study the photosynthesis of diatom cultures at different depths in the sea and also to measure the spring plankton production in Loch Striven. Steemann Nielsen (1932, 1937, 1951) also used the technique at various places in the Danish waters. A modification of this method

was used by Riley in both eutrophic and oligotrophic regions (1938, 1939, 1941a, 1941b) in extensive plankton investigations of the Tertugas region, western north Atlantic, Long Island Sound and Georges Bank. According to Riley (1938) Atkins' method of measuring phytoplankton production from phosphate consumption used in the English channel is applicable only during the first half of a bloom when the ratio of phosphate regeneration to phosphate consumption is negligibly small. And as there was no possible method for making a natural estimate of production, Riley resorted to the experimental method of suspending light and dark bottles containing plankton. In order to keep conditions as nearly natural as possible the bottles were filled with ordinary sea water and suspended at the same depth from which the samples were taken. The duration of the experiment was five to seven days, for, he found that the oxygen production during shorter periods was not sufficient to counterbalance the normal errors of sampling. Oxygen was determined at the start and end of the experiment. So, it was possible to determine both the oxygen production and oxygen consumption of which the former should be an expression of photosynthesis. However, he believed that the observed values of photosynthesis were smaller than the real and stated that the experiments give only minimal estimates of photosynthesis because of these sources of

errors. But later investigations with radioactive carbon and the data on oceanic production collected by the GALATHEA Expedition (Steemann Nielsen, 1952 and 1954) proved that this assumption is not quite correct. The results of Steemann Nielsen's investigations on the production of matter by phytoplankton in oligotrophic tropical areas were very different from those of Riley. The values obtained by the latter were at least 10 times higher. This discrepancy was suggested as the effect of differential growth of bacteria in the light and dark bottles due to the bactericidal effect of sunlight resulting in the over correction for respiration and corresponding over estimation of photosynthesis. But for eutrophic waters with experiments lasting 24 hours the data were comparable. Subsequently Vaccaro and Ryther (1954) showed that there is no difference between the growth or respiration of bacteria in light and dark bottles in experiments lasting for several days. Steemann Nielsen (1954 and 1955) also demonstrated by laboratory experiments with Chlorella and a marine diatom Thalassiosira that the effect of sunlight may be indirect by producing antibiotics by the plankton algae which increases with light in clear bottles reducing the bacterial activity in them. The difference in oxygen consumption between light and dark bottles was between 12 and 30 times higher than the oxygen production due to photosynthesis of the algae. So, it was presumed that due to

the production of antibiotics, plankton algae effect a reduction in the oxygen consumption of the bacteria in the light bottles. According to Ryther (1956) these experiments do not provide any direct demonstration of this phenomenon, whereas those of Vaccaro and Ryther (1954) gave direct contradictory evidence. Ryther (1956) also does not agree with Steemann Nielsen's main objection that production values obtained by long term light and dark bottles measurements are many times higher since values obtained by Ryther by such experiments are too low.

Now the controversy no longer exists as the order of magnitude of global oceanic primary production originally given by Riley (1944) has been reduced by a factor of about 10 (Ryther 1960; ^{as quoted by} Steemann Nielsen 1964; Valentine 1965; Koblents-Mishke et al., 1970). The most recent estimate by Koblents-Mishke et al. (loc.cit.) is $2.5 - 3.0 \times 10^{10}$ tons (gross production) and $1.5 - 1.8 \times 10^{10}$ tons (net production) of carbon per year, which is almost equal to the values given by Steemann Nielsen and Aabye Jensen (1957). According to Yentsch (N.S.), on the whole one can say that the oceans, as compared to the fertile regions of the earth, are virtually deserts. The oceans are productive only because of their size. The total production of the oceans is only 2 - 3 times of that on land, whereas ocean covers 75% of the planet.

In the Indian Ocean, prior to the International Indian Ocean Expedition (IIOE) (1962-65), DANA (1928-30), JOHN MURRAY (1933-34), DISCOVERY (1934) and ALBATROSS (1947-48) expeditions tried to evaluate the productivity from the nutrients and the standing crop of plankton. Gilson (1937) used the nitrate data of JOHN MURRAY expedition to estimate the organic production in the Arabian Sea in wet weight of algae. During the GALATHEA expedition primary production was measured by ^{14}C technique in the western Indian Ocean along the coast of Africa, equatorial part of the Indian Ocean in a section from Mombassa to Ceylon, Bay of Bengal and the Indo-Malayan waters (Steemann Nielsen (1952, 1954; Steemann Nielsen and Aabye Jensen 1957). These studies revealed that, in general, the primary production in the shallow coastal regions of the tropics is high. It was also observed that in the oligotrophic regions, where there was considerable addition of "new" water with high nutrient content into the photosynthetic zone, the daily organic production was high.

During the last decade there has been considerable progress in the study of primary production in the Indian Ocean and the environmental phenomena that regulate it. In connection with the IIOE, between 1959 and 1965 a large

number of ships belonging to several countries carried out intensive investigations in the Indian Ocean. The Arabian Sea and under the Australian programme, the 110°E longitudinal section were well studied (Ryther *et al.*, 1966; Jitts, 1969). After extensive measurements of primary production on board the ~~INTON~~ BRUUN, Ryther *et al.* (*loc.cit.*) showed that the western Indian Ocean is one of the most productive regions in the world. Some of the highest values ever recorded in the marine environment, excepting those from coral reefs and sea grass beds, were observed in the northern Arabian Sea off the Arabian peninsula. The observations in the western half of the Arabian Sea are summarized by Woester *et al.* (1967).

A large number of measurements were made on board VITIAZ which have been reported by Kabanova (1961, 1964, 1968). Besides, Burchall (1968) in the Agulhas Current region, Mitchell-Innes (1967) off South Africa and Jitts (1965) in the Australian waters also presented the results of their measurements.

Recently Krey (1973) has given an account of the distribution of chlorophyll and of potential assimilation in the Indian Ocean and Aruga (1973) has reviewed the relation of primary production in the Indian Ocean to chlorophyll and other environmental factors. As part of

the U.S.Antarctic Program El-Sayed and Jitts (1973) studied the primary production and standing stock of plankton in the south-eastern Indian Ocean.

Estimates of primary production in the different ecological zones of the Indian Ocean were presented by Neisnev (1969). Prasad, Banerji and Nair (1970) made a quantitative assessment of the primary production in relation to the potential fishery resources of the Indian Ocean and Cushing (1971) for the upwelling regions.

In addition to such direct measurements of primary production reports on phytoplankton pigments of the Indian Ocean by Ichimura and Fukushima (1963), Laird et al. (1964) McGill and Lawson (1966), Humphrey (1966) and Humphrey and Kerr (1969) provide a sound basis for the estimation of productivity in the Indian Ocean.

Several studies have been made in the coastal and off-shore regions of the Indian seas. Subrahmanyam (1959) measured the standing crop of phytoplankton by various methods and came to the conclusion that the production on the west coast of India is of a high order comparable to some of the most productive areas in the temperate regions. Prasad and Nair (1960, 1963) made a study of the seasonal variation and magnitude of production in the Gulf of Mannar on the south-east coast of India. The

results of investigations carried out at the Central Marine Fisheries Research Institute along the shelf regions of India and the Laccadive Sea, were discussed in relation to the potential living resources by Hair et al. (1968) and Hair (1970). Radhakrishna (1969) made a study of the primary productivity in the shelf waters of Alleppey on the south-west coast of India during the post-monsoon period and Shah (1973) presented the seasonal variation of phytoplankton pigments in the Laccadive Sea off Cochin.

The Cochin backwaters have been studied intensively in recent years for plant pigments (Qasim and Reddy, 1967), light penetration (Qasim, Bhattathiri and Abidi, 1968), organic production (Qasim et al., 1969) and nutrient cycle (Sankaranarayanan and Qasim, 1969). Besides the productivity of coral reefs (Hair and Pillai, 1972; Qasim, Bhattathiri and Reddy, 1972) of sea grass bed (Qasim and Bhattathiri, 1971) and liberation of particulate organic matter by coral reefs on an atoll (Qasim and Sankaranarayanan, 1970) have also been investigated.

Thus the Indian Ocean region is no longer the under-explored area it used to be, but is one of the few areas where international co-operation has been marshalled on an unprecedented scale for scientific exploration.

ENVIRONMENT

The area of the Indian seas where regular studies have been conducted lies between 73° and $79^{\circ} 30'$ E longitude and upto $10^{\circ}N$ on the south-east coast and $15^{\circ}N$ on the south-west coast and the Laccadive Sea.

South-east coast - Gulf of Mannar and Palk Bay

This area is exposed to two prevailing monsoons but the rainfall during the south-west monsoon is very little. Extremely turbulent conditions set in during May which continue sometimes even up to August. During this period the drift is from south to north and is particularly strong through the Pamban Pass reaching occasionally a velocity of 5-6 knots. On the contrary at this time Palk Bay is calm. With the onset of the north-east trade winds, generally during September, the Gulf of Mannar becomes comparatively calm. The direction of the drift is reversed and turbulent conditions prevail in Palk Bay. The north-east monsoon then sets in bringing rains and frequent cyclones which originate in the Bay of Bengal.

Seasonal variation of the hydrographic properties:

Fluctuations in the surface temperature of the sea water of Gulf of Mannar show a double oscillation. The minimum is in January which rises steadily till April and after May decreases. There is again an increase sometime

during September-October but not to that level of April. The lowering of the surface temperature of the coastal water has been brought about by the strong winds during the south-west monsoon season. The secondary peak is brought by the dying down of the south-west monsoon winds. During the period of observation the lowest temperature recorded in January was 26.1°C and the highest in April was 32°C. The secondary peak of September-October was 30.0-30.5°C. In Palk Bay the surface temperature is of a slightly lower order.

There is a regular seasonal cycle in the salinity in both Gulf of Mannar and Palk Bay. From a low value of 26‰ in January it gradually increases and remains high ($> 36\text{‰}$) until the middle of November. With the onset of north-east monsoon rains the salinity falls and lowest value is reached in December.

The nutrients at both areas are distinctly lower compared to temperate regions and further they do not show such great fluctuations as are characteristic of temperate waters. The monthly average phosphate values in Gulf of Mannar varied from 0.09 to 0.30 µg.at.P/l, whereas in Palk Bay the range was 0.14 to 0.25 µg.at.P/l.

The fluctuations in the values of nitrates, on the other hand, are greater in Palk Bay, with a range from

1.5 to 5.0 $\mu\text{g.at.}\text{Si/l}$. In the Gulf of Mannar monthly average values range from 1.9 to 4.7 $\mu\text{g.at.}\text{Si/l}$. The silicate values show wider fluctuations 3.3 to 14.8 $\mu\text{g. at.}\text{Si/l}$ in Gulf of Mannar and 5.3 to 17.9 $\mu\text{g. at.}\text{Si/l}$ in Palk Bay.

The percentage saturation of dissolved oxygen in the surface waters show greater fluctuations and a wider range in Palk Bay. In the earlier investigations Prasad (1954, 1956) found that the quantities of phytoplankton and oxygen saturation did not show any relationship and an apparently overall lower oxygen saturation in Palk Bay which he believed to be due to fewer coral reefs and hence lesser quantity of "imprisoned phytoplankton" or coral *zooanthellae* which produced considerable quantity of oxygen during photosynthesis.

The pH values generally vary from 8.4 to 8.7 at both the regions.

The total net plankton (Prasad loc.cit) in the Gulf of Mannar exhibit well-defined maxima and minima as well as differences from year to year. In general, the cycle is bimodal, with one peak between January and March and another during September-October. In Palk Bay also the distribution is bimodal. However, from January the total plankton steadily

increases upto May or June followed by a drop in July-August. Again there is an increase leading to a peak in September-October followed by a decline. The standing crop of plankton is often low during periods of turbulence.

The distribution pattern of total phytoplankton as observed from net collections reveal that in Gulf of Mannar there are three peaks which alternate with periods of low populations. In January the phytoplankton population is high followed by an appreciable decimation in February-March. The concentration increases during April-May and from June to August phytoplankton is low. It once again increases reaching a maximum either in October or in November. Against this abruptly fluctuating phytoplankton cycle in Gulf of Mannar, a more stable distribution is observed in Palk Bay. Starting from a rather low population in January the phytoplankton community increases steadily to a high level by May-June and remains high except for a slight decimation during July-August, upto October, after which there is an appreciable fall. Thus there is only a single prominent peak in Palk Bay in contrast to the three peaks in the Gulf of Mannar. The seasonal variation and succession pattern of the common phytoplankton are discussed separately.

Large quantities of Trichodesmium are noticed particularly in the summer months in Gulf of Mannar but are relatively scarce in the Palk Bay. In both regions Dinophyceae show two maxima with the primary peak in the summer months.

The distribution pattern of zooplankton differs widely at the two areas. When zooplankton is high in Gulf of Mannar it is relatively low in Palk Bay and vice versa. Palk Bay is characterised by a richer zooplankton.

South-west coast of India

The west coast of peninsular India forms a narrow belt of low land lying between the sea and the Western Ghats which extend throughout the whole length of the peninsula varying in width from 30 to 150 km inland and running in a direction north-northwest and south-southeast. There are a number of short rivers, many of which drain into the back waters of varying breadth occurring parallel to the coast.

The outstanding feature of the wind system in the Indian seas is a seasonal reversal of the direction associated with the two monsoons. During December to February, the northeast winds of the land origin prevail. The transition begins by about March and lasts through April. By the

middle of May the south-west monsoon winds of the oceanic origin are established, which continue to increase gradually until June when there is sudden strengthening. During July and August, the winds blew at their greatest strength and in September, the wind force decreases in preparation for the transition which lasts through October and November. Of the two monsoons, the south-west monsoon endures over a longer period in the Arabian Sea and is stronger and steadier than the north-east one. The onset of south-west monsoon is associated with overcast skies, showers and strong winds, as a result of which the solar insolation is cut off to a large extent. The incident radiation varies from 750 ly on a bright day to 150 ly on a cloudy day in July (Qasim et.al., 1968). Despite the humid conditions evaporation in the Arabian Sea is maximum during the south-west monsoon unlike the usual intense evaporation in winter. (Venkateswaran, 1956; Jagannathan and Ramasastry, 1964).

From the vertical density structure Sharma (MS) has inferred that the process of upwelling of the west coast of India in the deeper layers of about 90 m sets in by March and the upwelled water reaches the surface by May. The cessation of upwelling takes place in August and the reverse process of sinking begins by September. In a period of two months, the vertical movement is 80 m, giving rise

to an average intensity of upwelling of 40 m per month - i.e., 1.5×10^{-3} cm sec $^{-1}$ (Sharma, MS). The earlier authors (Banse, 1959; Rama Sastry and Myrland, 1959; Ramamirtham and Jayaraman, 1960) had inferred that upwelling off the south-west coast of India starts with the onset of the south-west monsoon. Regular upwelling is absent north of 15°N.

From July onwards cool water is present below 50 m, some times even at shallower depths which has a low oxygen content 50% or less of saturation appear to be the rule at the inshore regions throughout the entire upwelling season (Banse, 1968).

Seasonal variation of the hydrographic properties of the shelf waters off the west coast of India:

Time-series observations, during research cruises conducted by the Central Marine Fisheries Research Institute since 1957 off the west coast of India on board the Indo Norwegian Project vessels R.V. KALAVA and R.V. VARUNA, have provided data on the hydrology of the west coast. (Banse, 1959; Rama Sastry, 1959; Rama Sastry and Myrland, 1960; Ramamirtham and Jayaraman, 1960; Patil and Ramamirtham, 1963; Ramamirtham and Patil, 1965; Sharma, 1968; Banse, 1968).

The surface temperature all along the coast exhibits a double oscillation during the year with the primary maximum in April and the secondary in November. The corresponding

minima take place in July/August and December/January.

The low temperatures are spread over a longer period in the north than in the south. The low temperature in the monsoon period is due to reduction in the insolation due to the cloudy conditions and the monsoon rains and run off waters.

Generally, the coastal surface currents off the west coast of India set towards the south from February until late October or November and are reversed during the rest of the year.

There is no prominent seasonal variation in the dissolved oxygen content of the surface waters all along the coast but it does vary considerably in the subsurface layers. However, higher oxygen values of oxygen in the surface waters, in general, are noticed in June and September and lower values in January and July. The stratification of coastal waters during July and August in the depth range of 10 to 30 m results in the depletion of oxygen below the depth of stratification.

The depth of the mixed layer changes from a depth of more than 60 m in January–February to a depth less than 60 m by March–April. By May–June the mixed layer still moves to upper layers and the least depth of less than 20 m is observed in July–August. From then, it starts deepening to a depth of about 40 m by September–October.(Sharma, personal communication).

Studies conducted for prolonged periods at different centres had indicated that phosphate, nitrate and silicate show a seasonal fluctuation, the peaks in their concentration being attained during the south-west monsoon months. It is also found that when there is an abundant supply of these nutrients in the water the ratio of N:P is 15:1, the same as has been found in the temperate regions (Subrahmanyam, 1959).

Banse (1968) after reviewing the hydrography of the Arabian Sea shelf of India had inferred that the seasonal cycle of primary production is apt to be quite similar all along the west coast and that high photosynthetic rates can be expected during the south-west monsoon and later until the cool, deoxygenated subsurface water withdraws from the shelf. During the remainder of the year the density stratification in the surface layer will keep the photosynthetic rates low, near oceanic levels.

MATERIALS AND METHODS

Sea water samples were collected in 'light' and 'dark' bottles at fixed hours in the early mornings from six stations spread over a distance of 30 km in the Gulf of Mannar from July 1957 (Fig.1, stations G1 to G6). Care was taken that no air bubbles were left in the bottles. The bottles were then suspended at the same depth by means of 'cradles' from a platform erected for night fishing at the reference station G1. When the weather was rough, the bottles were attached to a pole, tied to an anchored drum. Samples were taken weekly from the reference station and biweekly from rest of the stations.

In a few trial series, oxygen content was determined at the start and after 24, 48, 72, 96 and 120 hours of the experiment. Production was found to be proportional to the time of exposure until about three days (Fig.2). Hence, experiments lasting 48 hours (for the first year) and 24 hours (for the subsequent years) were conducted. The difference in oxygen concentration between the light and dark bottles was converted into its carbon equivalent using PQ of 1.25 for obtaining gross production values. The difference between the initial and dark bottles was taken as the respiration and that between the light bottle and initial sample

Fig.1 showing the location of stations in the Gulf of Mannar (G1 to G6) and Palk Bay (P1 to P7). G1 is the reference station where most of the observations have been made for a continuous period.

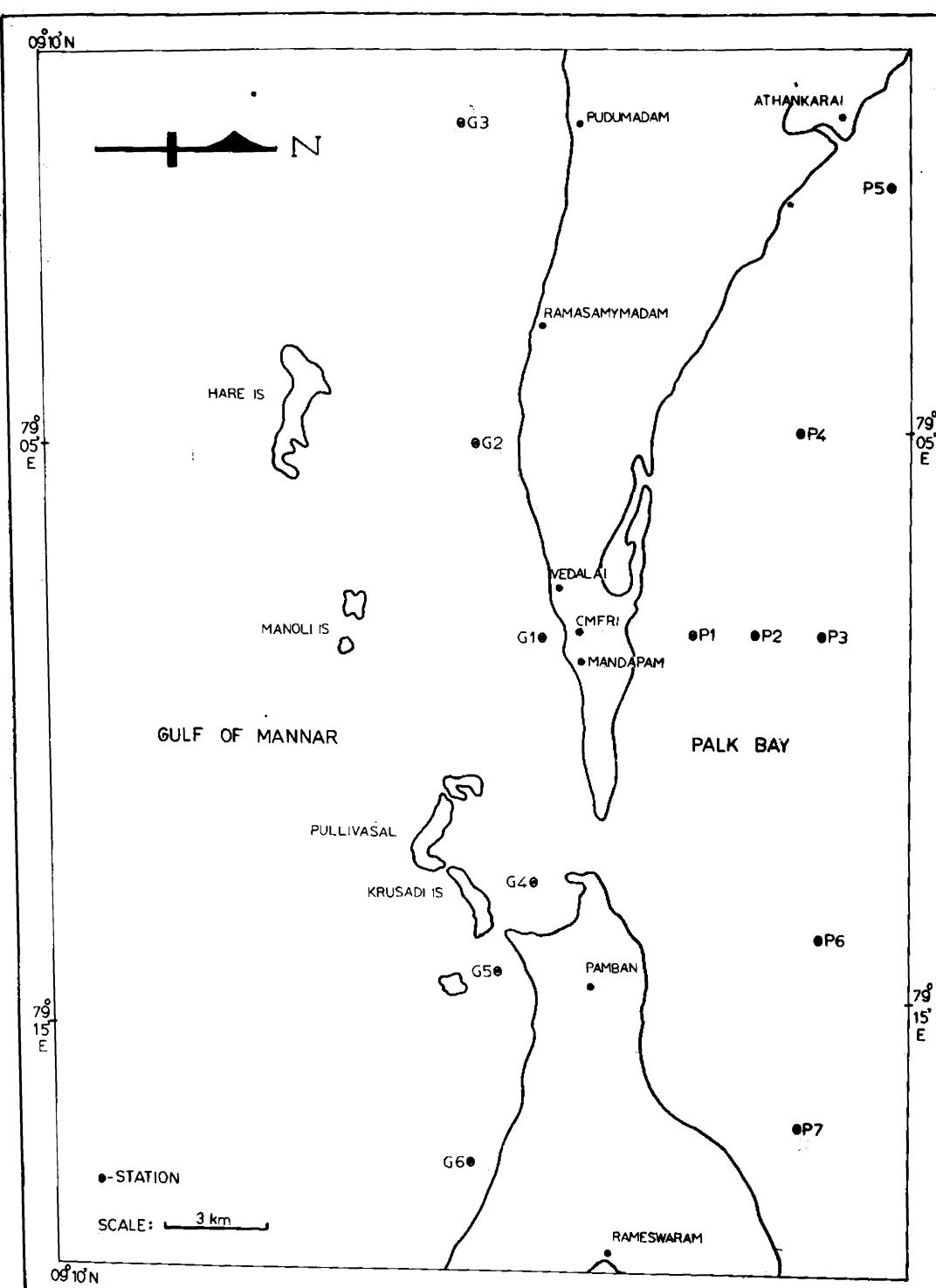
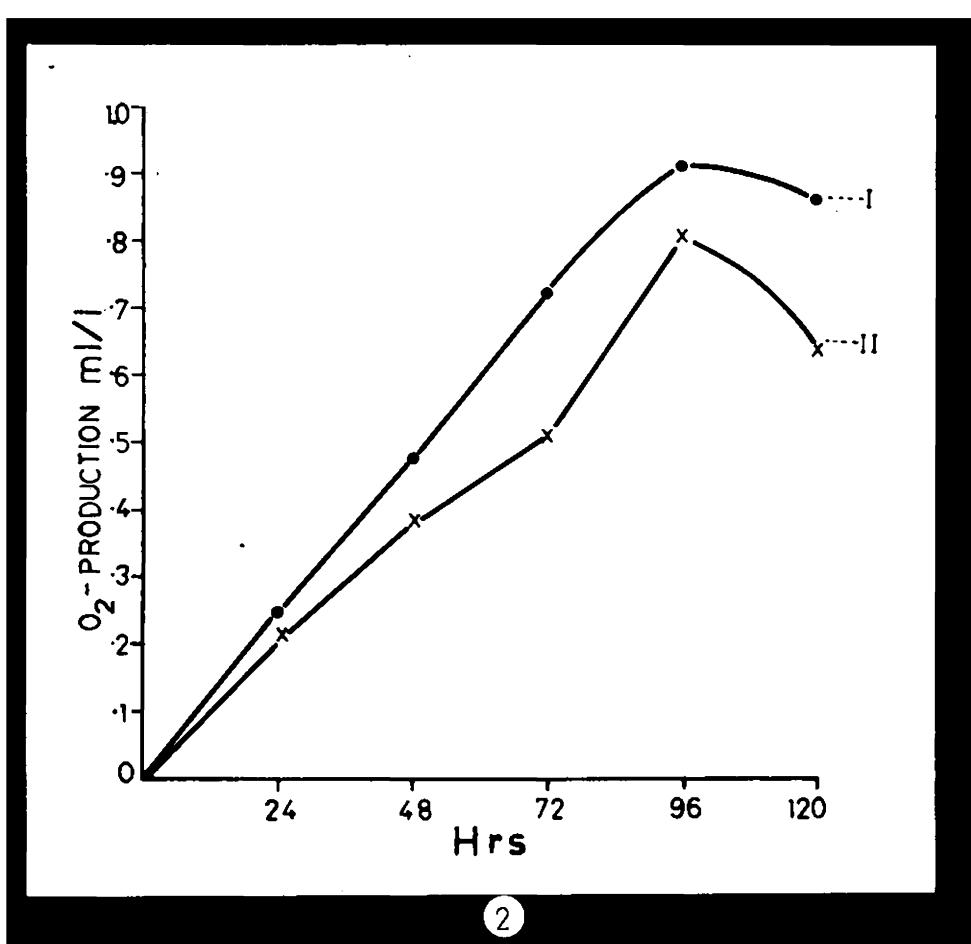


Fig.2. Gross oxygen production in the light and dark bottle experiments for varying hours of incubation (in situ).



(2)

was taken as the 'net community production' (Steemann Nielsen and Hansen, 1959). Analyses were carried out in the Gulf of Marnar till 1962. Salinity, temperature, pH, pigments, phosphates (total P in filtered and unfiltered samples and dissolved inorganic phosphate so as to determine the different phosphorus fractions including particulate P and organic P), nitrate and silicate were measured by standard methods.

One litre samples were filtered (Whatman and later Millipore filters), and the filter paper treated with 90% acetone and the plant pigments were measured by a Hilger and Watts Spekker Absorptiometer with a red filter (Richards with Thompson, 1952). (Spectronic 20 or a Unicam Spectrophotometer was used after 1964). During the earlier part of the study chromatographically pure chlorophyll *a* obtained from Sandoz (Switzerland) was used for calibration.

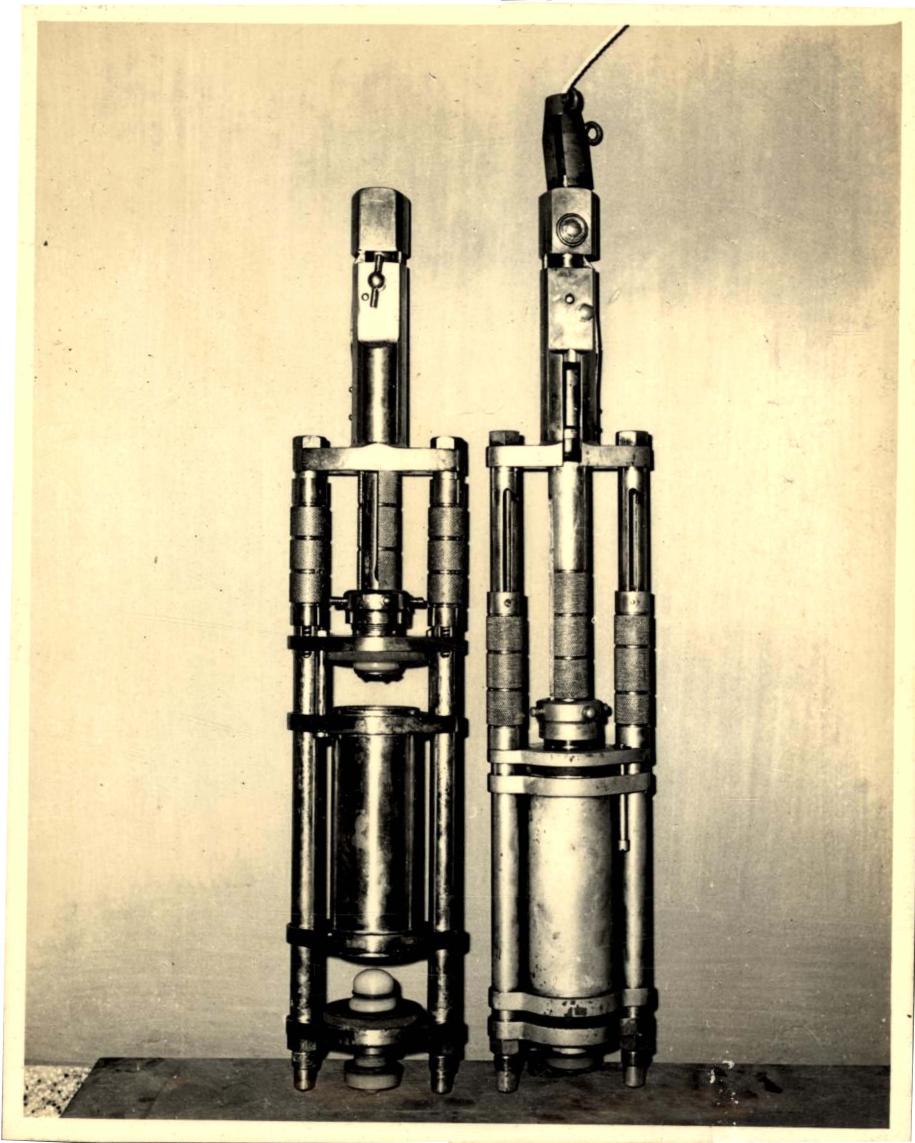
Parallel samples (1 litre) were sedimented, centrifuged and the phytoplankton cells were identified (upto species level wherever possible) and the total counts were taken in both initial and final samples; for this, bigger acid bottles were suspended. From this data growth kinetics of the total phytoplankton population and of the more common species were derived. All the above parameters were measured only in samples taken from the reference station. Only oxygen measurements were made for the rest of the stations.

Total organic nitrogen by the kjeldahl method in the initial and final samples were determined for over an year to examine the suitability of the values of protein obtained by this method as an index of productivity.

From 1965, the Indo-Norwegian Project placed a 28 metre long research vessel, R.V.VARUNA, at the disposal of the Central Marine Fisheries Research Institute for collection of hydrographic data and to conduct exploratory fishing. All the observations on the west coast and in the vicinity of the Laccadive and Maldive Islands and in the equatorial region were made on board this vessel during her research cruises.

^{14}C measurements were made first with ampoules and filters obtained from the International Agency for ^{14}C Determination, Charlottenlund, Denmark. Water samples were collected from the inshore regions of Mandapam (Fig.1) by a glass bottle with a 'snatch mechanism'. Insulated water bottle (Petersen type) with plexi glass inner cylinder (fig.3) or a Van Dorn sampler was used for deep water stations. In situ experiments were conducted in the shallow regions on the south-east coast from sunrise to noon or from noon to sunset. Most of the measurements on the south-west coast were by simulated in situ technique. For this two types of incubators have been used. One was a rotary incubator (fig.4) somewhat similar to the one used on board the

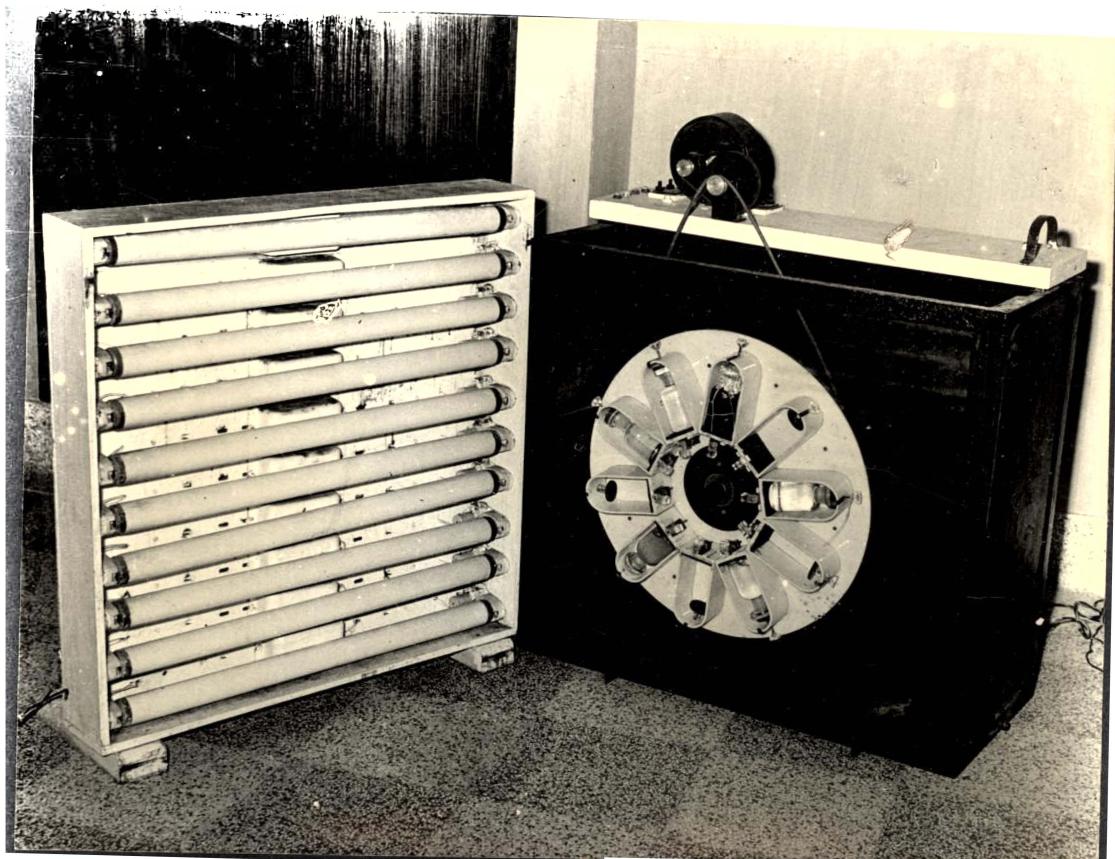
Fig.3. Insulated water bottles with plexi glass cylinder inside used on board for collection of samples for ^{14}C experiments (open and closed).



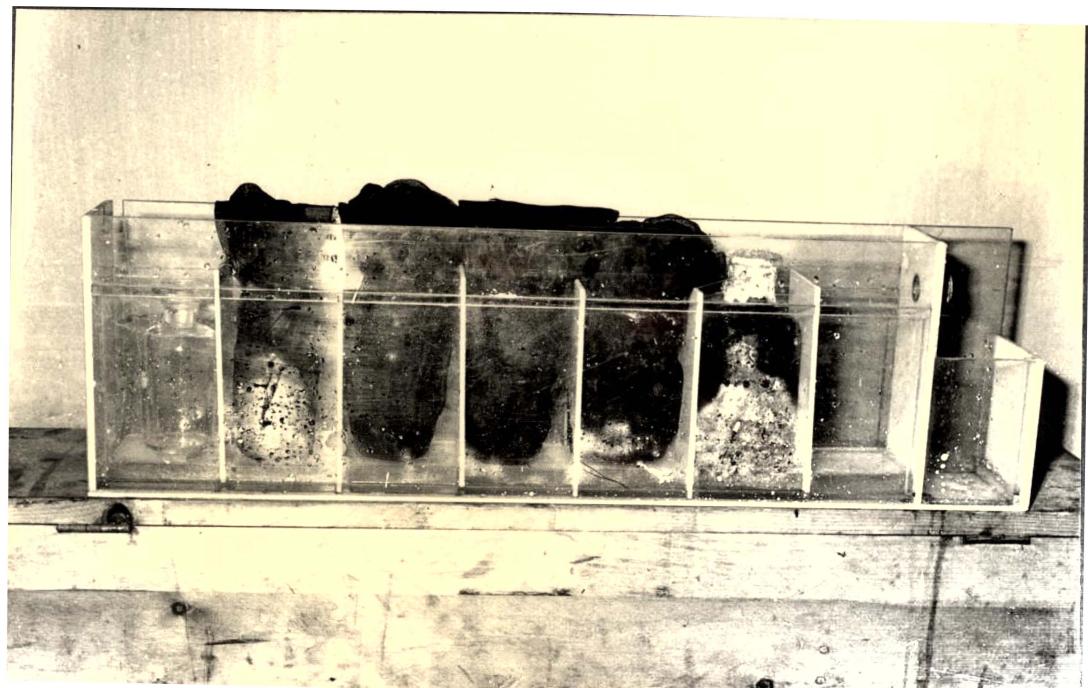
3

Fig.4. Rotary incubator and light panel for simulated in situ experiments. Glass plates with different layers of mesh screen serving as filters can be attached in front of each compartment for the bottles for varying the light intensity.

Fig.5. Sun light incubator with bottles. From left 100%, 60%, 30%, 16%, 1% and dark samples in simulated in situ technique can be seen.



4



5

GALATHEA (Steemann Nielsen and Aabye Jensen, 1957). The rotating disc was fabricated out of pvc and could hold 10 bottles on the front and two on the back (dark bottles). A fluorescent light panel provided a constant light λ (ca.20 klux).

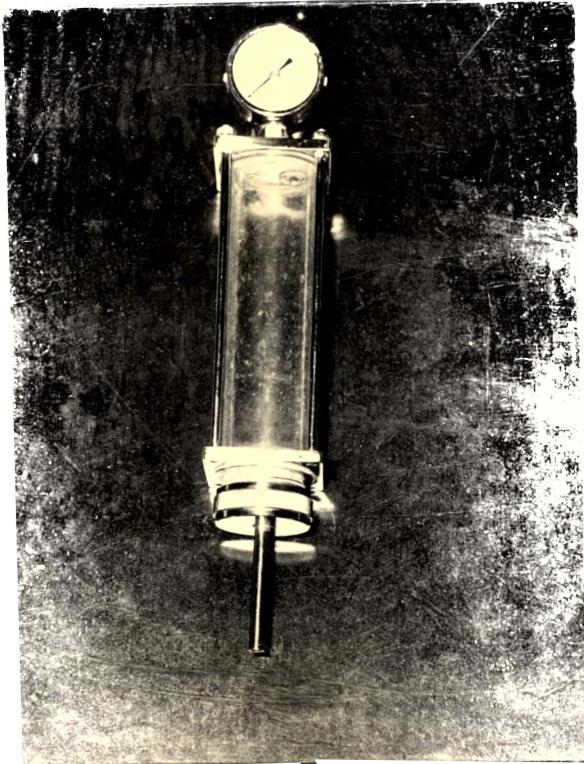
The second one was deck incubator in which sunlight was the source of illumination (Fig.5). Samples collected from the surface and 60%, 30%, 16% and 1% 'light depths' were exposed under mesh-screen neutral density filters transmitting the same percentage of incident radiations. The measurement of light penetration and calibration of neutral density filters were carried out by a Tinsley Irradiance Meter fitted with a blue/green filter (details of measurement given under the section on light penetration).

For incubation under constant light, samples were collected from surface and from depths at which 10% and 1% light intensity were recorded. Temperature correction was made at 5% per degree centigrade as the incubator was circulated with surface water.

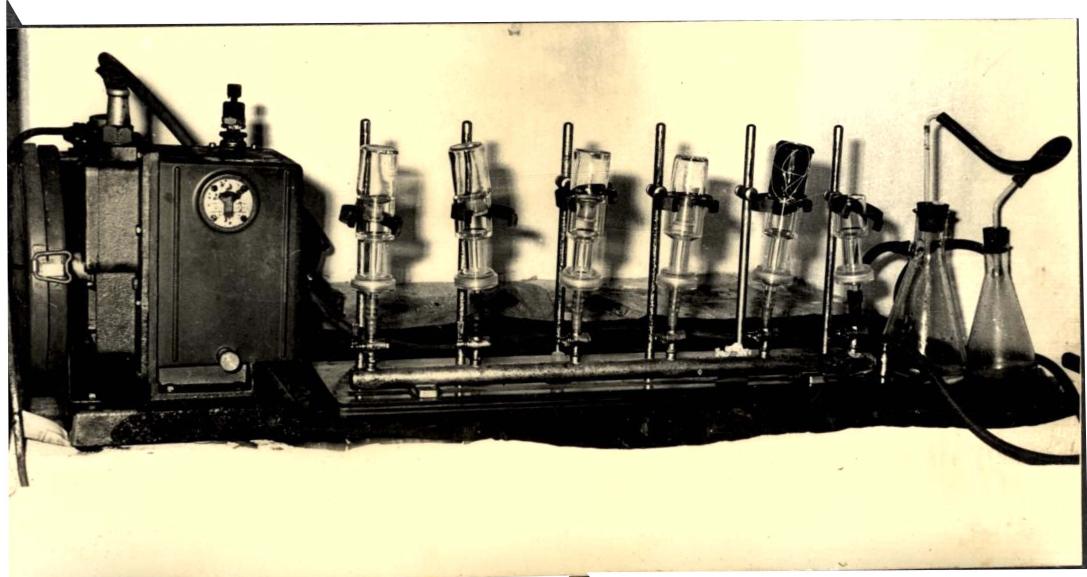
Samples were filtered either in a hand-filtration unit (Fig.6) with a cycle pump and in a manifold filtration unit (fig.7) under suction on board the vessel. Gettingen Membrane filters or Millipore HA filters of approximate 0.5μ pore size were used respectively for the two

Fig.6. Field Filtration unit for 36 mm membrane filters. Filtration by pressure developed with the aid of a bicycle pump.

Fig.7. Manifold filtering unit used on board the research vessel and in the laboratory. Millipore HA filters of 25 mm dia. are fitted on this. Filtration by suction.



6



7

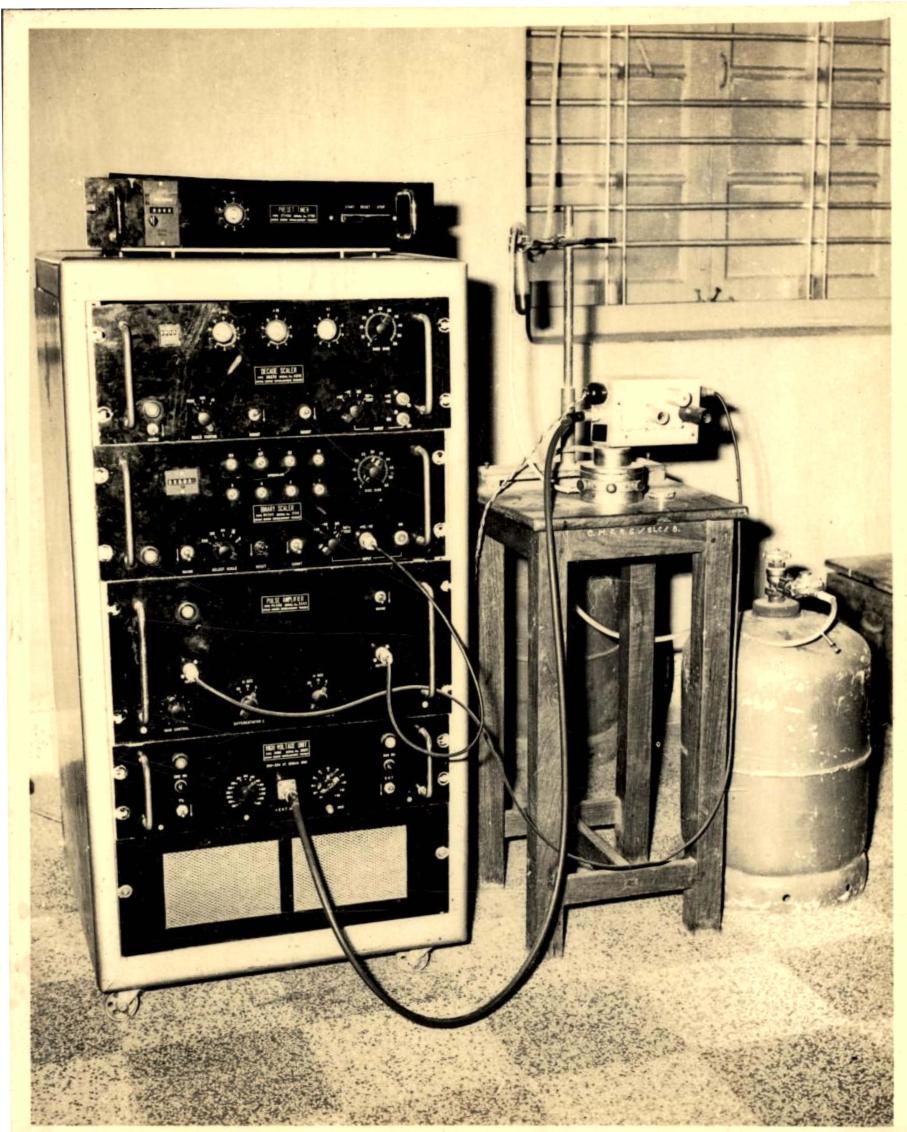
filtering units. Membrane filters were held by plastic holders to prevent buckling while drying. The filters were dried over silica gel^{and}, exposed to N₂I fumes before counting.

The samples counted at the International Agency have been subsequently corrected by a factor of 1.47 for error in standardisation (Steemann Nielsen, personal communication). With the availability of a Gas Flow Proportional Counting System (Fig.8) constructed by the Electronics Division of the Atomic Energy Establishment, Fremantle, standardisation and counting were done locally. The methods of standardisation and intercalibration trials carried out are given in the following section.

The production rate per unit volume was calculated by the corrected counts of the filtered sample as a fraction of the added activity and multiplying with the total CO₂ content of the water. In oceanic water it was assumed as 90 mg/l and for the inshore waters estimated from the tables of Dugay (1951) and Harvey (1955). The correction, for isotopic discrimination and interaction of respiration together was put at +10%.

Column production was calculated from in situ and simulated in situ experiments in the deck incubator by integration of the different rates at various depths using the formula of Dyson et al. (1965).

Fig.8. Gas flow proportional counting system. The windowless counter with the pre-amplifier in the centre. Gas used is 'Barshane', cooking gas. The electronic components on the left side consists of a pre-set timer at the top, two scalers - one decade and the other binary, a pulse amplifier and a high voltage unit. The plateau is rather broad and the working voltage is 3.8 to 3.9 k.v. The counter gave a zero-thickness counting efficiency of $61.1 \pm 2.7\%$



$$\text{Column production} = f_{1000} \left\{ \left(\frac{a+b}{2} \right) (d_1 - d_0) + \left(\frac{b+c}{2} \right) (d_2 - d_1) + \dots \right\},$$

where d_0 , d_1 , d_2 are the depths sampled;

a , b , c are the respective production rates in $\text{mg/m}^3/\text{day}$;

f a factor (1 for in situ and simulated in situ experiment). In samples incubated under constant light the empirical formula given by Steemann Nielsen and Aabye Jensen (1957) was applied to get the column production. In shallow waters, the values for the best depth (where maximum values are recorded) were multiplied by the actual depth, if it is less than the depth of the euphotic zone and half the product if it is more (Steemann Nielsen and Aabye Jensen, loc.cit.). Occasional checks with results of in situ experiments were made to assess the magnitude of variability in the different approaches. Column production obtained by simulated in situ technique was about 8% higher than the values obtained by in situ experiments and 14% than the tank method.

Standardization and intercalibration trials

An essential pre-requisite in the measurements of primary production by ^{14}C technique and the comparison of values obtained by different workers, is the reliable standardization of the ampoules.

When ^{14}C technique was first described by Steemann Nielsen in 1952, he followed the method of Calvin et.al. (1949) for making self-absorption curves. The values of primary production computed from the activity of the ampoule deduced from this method was found to be 3% lower if an end-window counter is used and 10% lower with a window-less counter (Steemann Nielsen, 1965). Hence all the values originally computed by the International Agency have been corrected accordingly.

The ampoules made in India at the Atomic Energy Establishment, Trombay, which were used for all the later measurements were standardized by three different methods, here and also by the original BaCO_3 technique at Copenhagen through the courtesy of Prof.E.Steemann Nielsen and Mrs.Ann Marie Bresta of the International Agency for ^{14}C Determination.

By the extrapolation of self-absorption curves

Jitts and Scott (1961).

Planchets of BaCO_3 varying from 0.5 to 6.0 mg/cm² each containing the same amount of ^{14}C activity were prepared in duplicate from the ampoules of each stock solutions. Each ampoule was diluted to 500 ml with a solution containing 1.36 g of Na_2CO_3 per litre of carbon dioxide-free distilled water. 0.5 ml aliquots of the diluted ^{14}C

solution were pipetted into seven conical flasks treated with "Desikote" and containing 0, 0.5, 1.5, 2.5, 3.5, 4.5 and 5.5 ml respectively of the same Na_2CO_3 solution used in diluting the ampoules. To these flasks 0.05, 0.1, 0.2, 0.3, 0.4, 0.5 and 0.6 ml of 6.26% BaCl_2 were then added.

The precipitate of BaCO_3 thus formed were allowed to stand for two hours with gentle swirling for every half hour. Planchets were prepared with each of these precipitates by their total transfer (aided by the coating of "Desikote") to Millipore HA filters mounted on the manifold filtering unit. The effective filtering area was 2.5 cm^2 . The planchets were sucked dry, dried over silica gel for 24 hours, weighed and counted. The following were the results obtained.

| <u>1. Thickness (ng/cm²)</u> | <u>Logarithm of activity (cpm)</u> |
|---|------------------------------------|
| 1.44 | 3.5603 |
| 2.32 | 3.4608 |
| 3.12 | 3.4477 |
| 3.80 | 3.3870 $Y = -0.0616x + 3.6287$ |
| 4.40 | 3.3432 |
| 5.56 | 3.3016 |

$$\text{Activity of ampoule by extrapolation} = 1.253 \times 10^6 \text{ cpm}$$

| <u>2. Thickness (ng/cm²)</u> | <u>Logarithm of activity (cpm)</u> |
|---|------------------------------------|
| 0.8 | 3.6219 |
| 1.0 | 3.5666 |
| 2.0 | 3.5344 |
| 3.0 | 3.4499 |
| 3.8 | 3.4376 Y = -0.05574x + 3.6411 |
| 4.9 | 3.3647 |
| 5.6 | 3.3369 |

$$\text{Activity of ampoule} = 4.376 \times 10^6 \text{ cpm}$$

Liquid scintillation counting method (Jitts and Scott, 1961):

In this the absolute activities (dpm) of the ¹⁴C stock solutions were determined by liquid scintillation counting in Australia through the courtesy of Dr.H.R.Jitts and by the candidate at the Atomic Energy Establishment, Trombay.

Indian Steak I - 11.4×10^6 dpm

-do- II - 11.2×10^6 "

International

Agency Steak C 82 - 7.45×10^6 "

The zero thickness counting efficiency of the gas flow counter (fig.8) was determined by counting 19 thin films of ¹⁴C labelled plastic mounted on membrane filters. The absolute activities of these filters were determined in the liquid scintillation counting system of CSIRO, Australia. Table 1 gives the counts and the absolute activities of the filters and the respective counting efficiency.

Table 1. Zero thickness counting efficiency of
the gas flow counter

| No. | Filter activity (cpm) | Absolute activity (dpm) | Efficiency % |
|-----|--------------------------|----------------------------|-----------------|
| 1 | 656 | 967 | 67.8 |
| 2 | 754 | 1208 | 62.4 |
| 3 | 738 | 1194 | 61.8 |
| 4 | 590 | 965 | 61.1 |
| 5 | 718 | 1240 | 57.9 |
| 6 | 486 | 830 | 58.6 |
| 7 | 780 | 1273 | 61.3 |
| 8 | 571 | 1024 | 55.8 |
| 9 | 839 | 1355 | 61.9 |
| 10 | 728 | 1150 | 63.3 |
| 11 | 679 | 1150 | 59.0 |
| 12 | 1019 | 1633 | 62.4 |
| 13 | 662 | 1070 | 61.9 |
| 14 | 768 | 1248 | 61.5 |
| 15 | 612 | 1034 | 59.2 |
| 16 | 719 | 1226 | 58.6 |
| 17 | 720 | 1115 | 64.6 |
| 18 | 512 | 841 | 60.9 |
| 19 | 639 | 1062 | 60.2 |

average counting efficiency 61.1 ± 2.7

Hence the activity of the stock solutions obtained by multiplying the absolute activity with the counter efficiency will be as follows:

Indian ampoule stock I - 6.96×10^6 cpm

-do- II - 6.90×10^6 "

International Agency
stock G 82 - 4.50×10^6 "

Biological method (Steemann Nielsen, 1965)

Cultures of Chorella pyrenoidosa and C. vulgaris obtained from the Botany Laboratory, Royal Danish School of Pharmacy, Copenhagen were grown in Osterlind's medium. In a series of experiments with different stock solutions consistent results were obtained.

Table 2. Zero thickness activities of different stock solutions obtained by the Biological method

| | Indian stock I | Indian stock II | International of Agency stock |
|---------|------------------------|------------------------|----------------------------------|
| 1 | 6.26×10^6 cpm | 7.23×10^6 cpm | -- |
| 2 | 6.33×10^6 " | 7.64×10^6 " | -- |
| 3 | 6.19×10^6 " | 7.23×10^6 " | -- |
| 4 | 6.50×10^6 " | 7.35×10^6 " | -- |
| 5 | 6.33×10^6 " | 7.20×10^6 " | -- |
| 6 | -- | 7.00×10^6 " | -- |
| Average | 6.32×10^6 cpm | 7.27×10^6 cpm | 4.55×10^6 |

A very close agreement is observed for the biological method and the liquid scintillation method which lends validity to each other. On the other hand the BaCO_3 technique of Jitts and Scott and the original BaCO_3 technique gave values, which were 32% each lower and higher respectively. Hence the added activity obtained by the scintillation method was followed for all the calculation due to its comparative simplicity once the counter has been calibrated for its zero thickness counting efficiency.

Intercalibration of stock solutions and counters

Intercalibration of primary production techniques have been conducted by biological oceanographers of several countries, in connection with the International Indian Ocean Expedition, sponsored by SCOR and UNESCO. Reports of such meetings (Doty, 1961 and 1962; Doty et al., 1965) provide a basis for the comparison of values obtained by different national techniques.

After the intercalibration trial at Hawaii in 1961, Dr.R.Raghun Prasad, who represented India gave some ampoules of ^{14}C of C.S.I.R.O., Australia. A series of concurrent in situ experiments were conducted in Palk Bay using the Australian ampoules and International Agency ampoules (Table 3). The results were disconcertingly divergent - C.S.I.R.O. ampoules giving consistently lower values - on the average only (45%).

**Table 3. Comparison of values of in situ measurements
in Falk Bay using Danish and Australian stock
solutions**

| No. | Period | Station | Depth (m) | Agency stock mgC/m ³ /hr | C.S.I.R.O. mgC/m ³ /hr | Stock % |
|-----|---------|---------|--------------|--|--------------------------------------|------------|
| 1. | Jun. 62 | P1 | 0 | 88.46 | 22.88 | 29 |
| 2. | " | " | 5 | 12.76 | 4.66 | 36 |
| 3. | Jul. | P2 | 0 | 195.16 | 11.76 | 6 |
| 4. | " | " | 4 | 45.42 | 20.56 | 45 |
| 5. | " | " | 8 | 4.37 | 1.73 | 30 |
| 6. | " | " | 0 | 114.60 | 36.13 | 32 |
| 7. | " | " | 4 | 4.44 | 1.36 | 31 |
| 8. | " | " | 8 | 3.12 | 0.99 | 32 |
| 9. | " | P7 | 0 | 64.52 | 13.16 | 20 |
| 10. | " | " | 6 | 12.26 | 4.86 | 40 |
| 11. | " | " | 12 | 0.74 | 0.43 | 57 |
| 12. | " | " | 0 (Dark) | 0.38 | 0.25 | 65 |
| 13. | " | " | 12 ("") | 0.29 | 0.23 | 79 |
| 14. | Jul. 62 | P5 | 0 | 45.26 | 15.76 | 35 |
| 15. | " | " | 4 | 20.91 | 7.82 | 37 |
| 16. | " | " | 8 | 3.23 | 0.81 | 25 |
| 17. | " | " | 0 (Dark) | 0.50 | 0.14 | 28 |
| 18. | " | " | 8 ("") | 0.16 | 0.15 | 99 |
| 19. | Jun. 63 | P1 | 0 | 10.75 | 5.05 | 47 |
| 20. | " | " | 4 | 8.67 | 4.73 | 55 |
| 21. | " | " | 8 | 0.41 | 0.23 | 56 |
| 22. | " | P5 | 0 | 17.20 | 7.78 | 45 |
| 23. | " | " | 4 | 26.91 | 11.20 | 42 |
| 24. | " | " | 8 | 12.46 | 7.08 | 57 |
| 25. | " | " | 10 | 5.20 | 3.24 | 62 |

According to Steemann Nielsen (personal communication) this large difference could be only due to the presence of toxic substances in the Australian stock solutions. It is likely that Cu in ionic form could have been introduced while diluting the original stock as shown by Steemann Nielsen and Wium-Andersen (1970), that when ampoules are made from commercially bought NaMnO_4 solutions by dilution with ordinary distilled water (instead of making C^{14}O_2 by distillation and using only glass distilled water) they contain ionic Cu which is poisonous for photosynthesis and growth of unicellular algae. Hence, though the Indian ampoules were made strictly according to the original method of Steemann Nielsen (1952) by the Radio-Chemistry Division of the Atomic Energy Establishment, it was thought desirable to make an inter-comparison and assess the magnitude of variability in measurements. Table 4 gives the results of in situ experiments in Palk Bay, using these ampoules along with the Agency ampoules.

Table 4. Comparison of values of primary production obtained by in situ incubation in Palk Bay during September-October, 1964, using Indian and International Agency ampoules standardised by scintillation method and counted in the gas flow proportional counter and the values computed by the Agency after correction for standardisation:

| No. | Indian ampoule (5/ μ c) (Proportional counter) | Agency ampoule (4/ μ c) (Proportional counter) | Agency ampoule (corrected) |
|--------------------------|---|---|-------------------------------|
| mgC/m ³ /hour | | | |
| 1. | 13.55 | 13.89 | 14.32 |
| 2. | 9.54 | 10.95 | 11.90 |
| 3. | 4.69 | 5.23 | 4.91 |
| 4. | 16.15 | 19.30 | 22.20 |
| 5. | 14.16 | 9.65 | 12.22 |
| 6. | 4.06 | 1.76 | 1.94 |
| 7. | 0.13 | 0.17 | 0.22 |
| 8. | 20.33 | 25.45 | 31.05 |
| 9. | 23.88 | 16.36 | 19.41 |
| 10. | 7.74 | 10.62 | 9.68 |
| 11. | 15.05 | 10.36 | 12.30 |
| 12. | 14.18 | 15.10 | 14.38 |
| 13. | 3.40 | 3.16 | 3.51 |
| 14. | 13.70 | 9.40 | 8.35 |
| 15. | 12.90 | 13.73 | 9.81 |
| 16. | 3.09 | 2.87 | 2.39 |
| 17. | 12.10 | 12.62 | 9.75 |
| 18. | 8.66 | 9.95 | 8.09 |
| 19. | 3.70 | 1.60 | 1.32 |
| 20. | 0.12 | 0.16 | 0.15 |
| 21. | 3.11 | 2.88 | 1.10 |
| 22. | 14.32 | 8.63 | 9.15 |
| 23. | 7.74 | 10.62 | 9.68 |
| 24. | 15.05 | 10.36 | 12.30 |
| 25. | 14.18 | 15.10 | 14.48 |
| 26. | 3.4 | 3.16 | 3.51 |

In vitro experiments with natural population did, not only show any reduction in photosynthetic rate but showed a slightly enhanced rate. Thus the primary production measurements have been taken after fully ascertaining the quality of the stock solution and proper standardization.

Samples taken at different times of the day from the same locality and exposed to constant light, so as to study the diurnal variation in the photosynthetic rate gave the following results:-

| Samples (hr) | Observed values mgO/m ² /hour | Computed by Agency mgO/m ³ /hour |
|-----------------|---|--|
| 06 | 2.49 | 1.78 |
| 08 | 2.58 | 1.85 |
| 10 | 4.50 | 3.20 |
| 12 | 3.50 | 2.58 |
| 14 | 4.91 | 4.43 |
| 16 | 3.90 | 2.72 |
| 18 | 3.48 | 2.40 |

The above series of experiments had proved conclusively that the ampoules supplied by the Atomic Energy Establishment, Trombay, and which are used for all the measurements since 1963 have no toxicity which suppresses the rate of photosynthesis. However, when these ampoules were tried with rather dense cultures of Skeletonema by

Prof. Steemann Nielsen, he observed a 5% lower rate. This prompted him to suggest that in less dense cultures as well as in situ experiments our ampoules might give lesser values, compared to the Danish ampoules.

Comparison of values of primary production measured by oxygen and ^{14}C techniques in different conditions:

In order to have a proper reconciliation of the values of primary production obtained by the oxygen and ^{14}C techniques, it is essential to have direct comparison of values of concurrent experiments. But data on these are very scanty and even the available results are mainly from cultures.

In Table 5A, B and C three sets of results are presented from:

- (a) In situ experiments in a coastal area at times of high and low production. (Table 5A)
- (b) Coral colonies with symbiotic *zooxanthellae*,
(Table 5B)
- (c) In vitro culture of a green flagellate, Tetraselmis gracilis at different stages of growth, (Table 8).

Some authors tend to take values of ^{14}C assimilation as net production (cf. Qasim et al., 1969). This assumption was because the discrepancies between net production obtained from their oxygen experiments were less with ^{14}C than with gross production. Steemann Nielsen (1960, 1963 and 1964)

has emphasized that the values obtained by ^{14}C technique is somewhere between gross and net production and for getting either values a correction factor has to be applied. The results in Table 5A clearly indicate that values from ^{14}C method need not necessarily be lower than those from oxygen method. In fact, in the coastal waters when the rate of production is high, values of gross production obtained by the oxygen method ^{are} been lower, probably due to the influence of respiration of zooplankters which happen to be in the light bottle.

McAllister et al. (1961) who studied primary production in a coastal area by enclosing the water in a large volume plastic sphere, observed large discrepancies. They consider that in the coastal water ^{14}C method gives low results due to the photosynthetic assimilation of non-labelled carbon. After reviewing the various aspects of the problem, Strickland (1960), while stating that ^{14}C values are nearer to net production than gross, has stressed that it is not established as a universal rule for all marine photosynthesis.

The results obtained suggest that in coastal areas where the rate of production is high, short-term experiments with ^{14}C give values which are nearer to gross production, whereas in waters with low rates, it is nearer to net production. In experiments with flagellates, the values

are less than net production due to loss by excretion or at the time of filtration (Table 8). Only in experiments of long duration (24 hours) ^{14}C gives measurements of net production (Steemann Nielsen, 1964). But such duration is normally avoided because of other complications especially in oceanic environment.

Experiments with the corals (Table 5B), though not strictly comparable to those with natural populations of phytoplankton or cultures, give an idea of the relative rates even under very special conditions. Each specimen taken alive from a nearby reef was acclimatised to the aquarium conditions (details given in appendix 3 (Pillai and Nair, 1972) and was subjected to two sets of experiments. (1) Determination of gross production by changes of oxygen in light and dark jars; (2) Determination of the ^{14}C uptake by the symbiotic zooxanthellae alone. Since the gross production is a function of the respiration of the entire coral colony, whereas ^{14}C uptake represents only the contribution by the zooxanthellae, the usual correction for respiration is inadequate in this case. Hence the respiration of the entire colony obtained from dark bottle correction has been added to ^{14}C values to get the 'adjusted gross production' by the latter method. The contribution of boring

algae which has not been determined and which is sometimes very significant, loss of zooxanthellae during separation, inhibition of photosynthesis from too much light (as zooxanthellae are normally conditioned to the milder intensity while inside the corals), loss of photosynthetic products by cell lysis are some of the factors that could individually or collectively affect the results. Hence a real comparison is untenable. However, in about 50% of the cases the results are fairly comparable. Only in two cases the ^{14}C values are higher, whereas in rest of the experiments they were lower. Percentage realised by ^{14}C against net production measured by light bottle ranged between 40-80%. In Goniastrea pectinata and Genipora stokesi ^{14}C uptake was more than the net production measured by oxygen technique (150 and 103% respectively) (Pillai and Hair, 1972, Table V).

Oxygen and ^{14}C technique do not always yield concordant results as photosynthesis consists of a complex of reactions which do not have fixed relationships with each other and the two methods measure the rate of different reactions; besides fixation of ^{14}C by carboxylation reactions and release of extra cellular products of photosynthesis bring in a certain amount of disparity (Pogg, 1963 and 1969).

Table 5. Comparative values of primary production by oxygen and ^{14}C technique.

(A) In situ experiments:

| No. | Station | Depth | ^{14}C mg/m ² /day | O_2 | O_2 | Ratio $\text{O}_2 / ^{14}\text{C}$ | |
|-----|------------|-------|--|--------------|--------------|------------------------------------|---------|
| | | | | (PQ=1) | (PQ=1.25) | PQ=1 | PQ=1.25 |
| 1. | 61 | 0 | 390 | 393 | 316 | 1.01 | 0.81 |
| 2. | " | 5 | 188 | 163 | 131 | 0.87 | 0.70 |
| 3. | P1 | 0 | 37 | 63 | 50 | 1.70 | 1.35 |
| 4. | " | 4 | 41 | 32 | 26 | 0.78 | 0.63 |
| 5. | " | 8 | 53 | 210 | 169 | 3.96 | 3.19 |
| 6. | Laccadives | 0 | 13 | 93 | 74 | 7.15 | 5.69 |
| 7. | " | 0 | 8 | 135 | 108 | 16.87 | 13.50 |
| 8. | " | 0 | 56 | 135 | 108 | 2.41 | 1.93 |
| 9. | P1 | 0 | 639 | 564 | 452 | 0.88 | 0.71 |
| 10. | " | 8 | 143 | 81 | 65 | 0.57 | 0.45 |

(B) Experiments with live corals:

| No. | Species | Gross produc- tion mgC | Respiration mgC | ^{14}C values adjusted to gross (mgC) | $\text{O}_2/^{14}\text{C}$ |
|-----|-------------------------------|---------------------------|--------------------|---|----------------------------|
| 1. | <u>Acropora cervinosa</u> | 2.99 | 1.29 | 2.58 | 1.16 |
| 2. | <u>A. erythraea</u> | 2.66 | 0.97 | 1.95 | 1.36 |
| 3. | <u>Cyphastrea microphalma</u> | 1.13 | 0.47 | 1.04 | 1.09 |
| 4. | <u>Favia pallida</u> | 1.51 | 0.56 | 0.95 | 1.59 |
| 5. | <u>Favites abdiata</u> | 0.66 | 0.23 | 0.51 | 1.29 |
| 6. | <u>Goniastrea pectinata</u> | 0.55 | 0.28 | 0.63 | 0.87 |
| 7. | <u>Goniopora stokesi</u> | 3.16 | 1.0 | 3.28 | 0.98 |
| 8. | <u>Pocillopora damicornis</u> | 3.94 | 1.31 | 3.39 | 1.16 |
| 9. | <u>Porites selida</u> | 1.05 | 0.29 | 0.49 | 2.14 |

THE PHYTOPLANKTON OF THE INSHORE WATERS OF MANDAPAM

Qualitative and quantitative studies on the phytoplankton of the inshore waters of Mandapam were based on centrifuged water samples and net collections. Sixty species commonly occurring in the plankton were classified into bio-geographical groups and the general character of the diatom flora of the Gulf of Mannar and Palk Bay were described by Prasad and Nair (1960). It was found that the biological spring falls in May or some time by the end of April and the secondary maximum occurs in October or November.

Fifteen species are well-represented in the collections and most of these are forms with a summer maximum but remain more or less important throughout the season while a few are with a distinct 'spring' and 'autumn' maxima. It is also found that Palk Bay is having a larger breeding stock of autochthonous diatoms which are mostly neritic, whereas in the Gulf of Mannar there are more littoral and oceanic forms.

Most of the species occurring both in the Gulf of Mannar and Palk Bay and constituting the bulk of net collections are Chaetoceros spp., Rhizosolenia alata, R. imbricata, Thalassionema nitzschiaeoides, Phalassiothrix fraenfeldii, Bacteriastrum hyalinum, Riddalphia sinensis.

Species such as Thalassiosira coromandeliana, Guinardia flaeidea, R.styliformis, R.calcar-avis, R.castracanei, Hemiaulus sinensis, Bacteriastrum varians, Chaetoceros denticulatum, Climacesphaenia elongata and Asterionella japonica are also found in good numbers especially in Palk Bay. Tropical oceanic forms such as Chaetoceros eccentricus, with Verticella, Ditylum brightwelli, Biddulphia sinensis and Hemidiscus hardmannianus are found very commonly in the Gulf of Mannar. Prasad (1954) observed blooms of single species of Rhizosolenia, R.imbricata in February and R.alata in March during two succeeding years in the Gulf of Mannar, whereas during the summer as well as in August-September maxima more than one genus and several species were noticed flowering. He also observed that there are variations in the species composition of the diatom maxima taking place at different months of the year.

Seasonal and quantitative variation of the common phytoplankters of Mandapam:

Of the sixty two species of diatoms recorded from this area, fifteen species are well-represented in the net collections. Most of these are forms with a summer maximum but remain more or less important throughout the season while a few are with a distinct 'spring' and 'autumn' maxima. Seasonal occurrence of the more common species are discussed below:

Asterionella japonica has a sparse occurrence in the Gulf of Mannar except during the summer. In Palk Bay it forms an important constituent in the plankton from February to April and from June to November with the maximum in August when it appears in blooms. There seems to be a regularity in their occurrence in Palk Bay during consecutive years whereas it is not the case in the Gulf of Mannar. In temperate waters it is considered as one of those erratic organisms with extremes of abundance which are not seasonal (or even annual) in occurrence but are based on more or less fortuitously favourable combinations of the required conditions (Allen 1945).

Bacteriastrum hyalimum occurs in both the areas during summer blooms and also during the latter part of the year. B. varians is a more warm water species that forms one of the constituents of the phytoplankton bulk of April-May and sometimes in August. In net collections it appears in swarms in both the areas from May to June. The genus Bacteriastrum can be considered as one of the four dominant genera that makes up the diatom bulk of this area.

Biddulphia sinensis is considered as a tropical neritic species which has invaded the temperate waters where it has become a permanent member of the plankton. It has also been

used as an indicator of currents and for determination of the rate of flow of currents (Lebour 1930). Being a tropical species it is more common than *B. nobiliensis*. In the Gulf of Mannar it occurs almost throughout the year with the maximum during summer.

Chaetoceros indicus was described for the first time from the plankton of the Madras coast (Subrahmanyam 1946). It is abundant in net collections in both the areas and forms one of major constituents of the diatom maxima. It is comparatively more abundant in Palk Bay. In the Gulf of Mannar it occurs in small numbers intermittently from April to December.

Chaetoceros lascinosus is a prominent species in Palk Bay occurring regularly during both peaks and is almost totally absent at other times of the year. In the Gulf of Mannar it occurs intermittently during May to December.

Chaetoceros lorenzianus occurs in the Gulf of Mannar almost throughout the year and form a major part of the diatom population and appears in large number during the diatom blooms. *C. lorenzianus* together with *C. lascinosus* form the bulk of *Chaetoceros* abundance. *C. lorenzianus* occupies the place of *C. debilis* in temperate waters being the most abundant form of *Chaetoceros* when taken on a round-the-year basis though occasionally stray blooms of *C. lascinosus* may occur.

Chaetoceros peruvianus occurs commonly in the Gulf of Mannar from April to December at intervals. In November it occurs persistently with a regular succession. In Palk Bay it is present in fairly good numbers from May to November.

Coscinodiscus gigas occurs in both places almost throughout the year in few numbers. In June it occurs more commonly in the Gulf of Mannar.

Hemidiscus hardmannianus has a greater abundance in the Gulf of Mannar than in Palk Bay. It occurs throughout the year at intervals, and is very common in the plankton with maximum abundance in March-April in the Gulf of Mannar.

Rhizosolenia alata is a temperate oceanic species which occurs in both the areas exhibiting wide fluctuations.

Rhizosolenia imbricata occurs in the Gulf of Mannar at intervals. It is commonly found in the net collections in February, March and in November. In Palk Bay it forms a dominant member of the genus from June to September.

Thalassiosira nitzschicoides occurs almost through the year in the Gulf of Mannar with occasional absence. But in Palk Bay it appears only during the two major blooms. Though a neritic form it is circum-global and its distribution pattern supports the contention of some investigators that neritic species can survive in oceanic environments well, if they are transported there (Smayda, 1958).

Thalassiothrix frauenfeldii is considered as the most important species occurring in the plankton of both the areas. In the Gulf of Mannar it occurs almost throughout the year, and is a dominant member of the summer blooms. The maximum occurrence is in April/May but in October also it occurs in good numbers. T.frauenfeldii is considered an oceanic temperate species preferring warmer waters.

Littoral forms such as Pleurosigma spp. and Navicula spp. are more abundant during or immediately after the period of turbulence.

Palk Bay is more or less an enclosed area and there is a relatively more regular seasonal succession of species which is probably an indication of a larger autochthonous breeding stock of diatoms. On the other hand Gulf of Mannar has conspicuously more oceanic species which supports the observations of Prasad (1954) about the possible incursion of oceanic surface waters in the coastal area during June-August as evidenced by high salinity and low silicate and also the presence of open ocean planktonic animals. The relative abundance of phytoplankters at station G1 is given in Table 6.

Table 6. Seasonal variation and relative abundance of
the phytoplankters in Gulf of Mannar

| BACILLARIOPHYCEAE CENTRALES | J | F | M | A | M | J | J | A | S | O | N | D |
|---------------------------------------|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. <u>Meiosira sulcata</u> | R | P | R | R | C | R | - | R | - | - | P | R |
| 2. <u>Hyalodiscus subtilis</u> | - | - | - | - | - | - | R | R | P | - | - | - |
| 3. <u>Stephanopyxis palmarum</u> | C | P | R | - | - | - | - | - | - | - | - | - |
| 4. <u>Skeletonema costatum</u> | - | - | - | - | - | - | - | R | C | R | - | - |
| 5. <u>Thalassiosira subtilis</u> | C | R | - | - | - | - | - | - | * | P | R | |
| 6. <u>Geschinodiscus</u> spp. | P | C | C | P | - | R | C | P | R | - | F | F |
| 7. <u>Geothraea hystrix</u> | - | - | - | - | - | - | - | C | P | - | R | |
| 8. <u>Landeria annulata</u> | P | - | - | - | P | - | - | - | F | R | R | |
| 9. <u>Schroederella delicatula</u> | - | - | - | - | - | - | P | R | - | F | R | |
| 10. <u>Leptocylindrus danicus</u> | - | - | - | - | - | - | R | P | * | C | A | |
| 11. <u>L. minimus</u> | P | P | P | - | - | - | - | - | R | C | A | |
| 12. <u>Quinardia flaccida</u> | P | R | - | - | - | - | - | - | P | - | - | |
| 13. <u>Rhizosolenia Stellerfothii</u> | P | - | P | - | - | - | R | R | P | R | P | |
| 14. <u>R. robusta</u> | - | - | - | - | - | P | P | - | - | - | - | |
| 15. <u>R. imbricata</u> | P | - | P | - | - | - | - | R | P | R | - | |
| 16. <u>R. styliformis</u> | P | - | P | - | - | - | R | R | P | C | R | |
| 17. <u>R. setigera</u> | - | - | - | - | - | - | R | R | - | R | R | |
| 18. <u>R. alata</u> | P | R | A | - | - | - | - | - | P | P | R | |
| 19. <u>R. calcar-avis</u> | P | - | - | - | - | - | R | - | P | - | - | |
| 20. <u>Bacteriastrum hyalinum</u> | C | - | P | A | - | - | R | R | P | R | P | |

| | J | F | M | A | M | J | J | S | O | N | D |
|--------------------------------------|---|---|---|---|---|---|---|---|---|---|---|
| 21. <u>Chaetoceros coarctatus</u> | - | - | - | - | - | - | - | P | P | - | - |
| 22. <u>C. peruvianus</u> | P | - | - | - | - | - | - | R | P | R | - |
| 23. <u>C. lorenzianus</u> | - | - | - | - | - | - | R | - | - | P | - |
| 24. <u>C. diversus</u> | R | - | P | - | - | R | - | - | P | R | |
| 25. <u>C. laevis</u> | - | - | - | - | - | - | - | P | - | R | |
| 26. <u>C. indicum</u> | - | - | - | C | A | C | C | P | - | P | - |
| 27. <u>C. spp.</u> | R | R | A | B | - | - | - | B | C | - | |
| 28. <u>Streptotheca</u> sp. | - | - | - | - | - | - | - | - | R | R | |
| 29. <u>Bellereachea malleus</u> | R | - | - | - | - | R | - | - | P | - | R |
| 30. <u>Ditylum brightwelli</u> | R | - | - | - | R | P | - | - | R | R | |
| 31. <u>Triceratium favus</u> | - | - | R | - | - | R | - | - | R | R | |
| 32. <u>Biddulphia sinensis</u> | R | R | R | R | C | A | A | P | R | - | R |
| 33. <u>B. nephthaliensis</u> | R | - | R | P | R | R | - | - | R | R | |
| 34. <u>Hemiaulus hanekii</u> | R | - | - | - | - | - | - | R | R | R | |
| 35. <u>Hemidiscus hermannianus</u> | C | R | R | R | - | - | R | - | - | R | R |
| PENNIALES | | | | | | | | | | | |
| 36. <u>Rhabdonema mirificum</u> | R | P | R | P | P | R | - | C | R | R | - |
| 37. <u>Grammatophora marina</u> | - | P | R | - | - | R | - | - | - | - | P |
| 38. <u>Liomophaera abbreviata</u> | - | R | P | - | - | - | - | C | - | R | - |
| 39. <u>Climacosphenia moniligera</u> | R | R | P | R | - | - | C | R | P | P | R |
| 40. <u>Fragilaria oceanica</u> | - | - | - | - | - | - | - | P | - | - | |

| | J | F | M | A | N | J | J | A | S | O | N | D |
|--|---|---|---|---|---|---|---|---|---|---|---|---|
| 41. <u>Synedra</u> spp. | - | R | - | - | - | - | - | - | F | R | - | - |
| 42. <u>Thalassionema</u> <u>nitzschiaoides</u> | F | R | F | R | C | R | F | - | R | R | C | P |
| 43. <u>Thalassiothrix</u> <u>frauendorfii</u> | R | F | F | C | C | R | - | - | R | F | F | R |
| 44. <u>Asterionella</u> <u>japonica</u> | R | G | C | F | - | G | R | A | R | R | R | R |
| 45. <u>Cocconeis</u> spp. | R | R | F | R | R | R | F | R | R | R | F | R |
| 46. <u>Achnanthes</u> spp. | - | - | - | - | - | - | - | R | F | R | - | - |
| 47. <u>Gyrosigma</u> <u>balticum</u> | - | R | - | - | - | - | R | - | R | F | - | - |
| 48. <u>Pleurosigma</u> <u>normanii</u> | C | C | C | B | C | R | - | R | F | R | R | F |
| 49. <u>Diploneis</u> <u>weissflogii</u> | R | R | - | - | - | R | R | R | - | R | R | - |
| 50. <u>Navicula</u> spp. | F | F | C | F | R | C | R | - | R | C | R | F |
| 51. <u>Pinnularia</u> spp. | - | - | - | - | - | - | R | R | - | - | - | - |
| 52. <u>Amphiprora</u> <u>gigantea</u> var. <u>sulcata</u> | - | - | - | - | - | - | - | - | - | R | R | - |
| 53. <u>Amphora</u> sp. | R | R | - | - | - | R | F | R | - | - | R | - |
| 54. <u>Eunotia</u> sp. | - | - | - | - | - | - | - | - | - | R | R | - |
| 55. <u>Gymbella</u> sp. | R | F | R | F | R | R | - | F | R | - | R | R |
| 56. <u>Bacillaria</u> <u>paradoma</u> | - | F | - | - | - | - | R | R | - | - | R | - |
| 57. <u>Hantzschia</u> <u>closterium</u> | R | G | C | F | - | - | R | F | - | F | R | R |
| 58. <u>H.</u> <u>sigma</u> | R | R | R | - | - | - | - | - | - | R | R | - |
| 59. <u>H.</u> <u>longissima</u> | - | - | - | - | - | - | - | - | F | - | R | - |
| 60. <u>H.</u> <u>seriata</u> | F | - | F | - | - | - | R | R | - | R | F | - |
| 61. <u>H.</u> spp. | - | A | C | - | - | R | F | F | R | R | R | R |
| 62. <u>Surirella</u> spp. | - | R | - | - | - | - | - | R | - | R | R | R |

| BINOPHYCEAE | J | J | A | N | J | J | A | S | O | N | D |
|----------------------------|---|---|---|---|---|---|---|---|---|---|---|
| 63. <u>Ceratium</u> spp. | R | - | - | - | - | - | - | R | C | F | R |
| 64. <u>Peridinium</u> spp. | - | - | - | - | - | - | - | F | R | R | R |

B = Bloom (more than 1,00000 cells)

A = Abundant (more than 10,000 cells)

C = Common (more than 1,000 cells)

F = Few (more than 500 cells)

R = Rare (less than 500 cells)

- = Absent

General growth kinetics of the total population and of
the more common species of diatoms:

The mean generation time and growth constant have been studied elsewhere for a number of phytoplankters especially diatoms grown in cultures. But very little work has been done with marine phytoplankters in the natural environment. In fact, no results have been reported from the Indian seas.

The phytoplankters increase in numbers by cell division. The individual cells have a variable generation time when they double themselves. This changes according to the environmental conditions and the mean value for a division time is expressed by the equation:

$$\ln.n_t = \ln.n_0 + kt$$

where n_0 is the initial number of cells, n_t is the number of cells at the end of time t expressed in hours and k a constant that depends on the organism and the environment. If t_g is the mean generation time for a cell in hours,

$$t_g = \frac{0.7}{k} \quad \text{or} \quad k = \frac{0.7}{t_g} \quad (\text{Strickland, 1960}).$$

So by taking the natural logarithm (ln) of cell numbers at the initial and final phase of the experiment the growth constant (k) and mean generation time (t_g) can be calculated.

According to Strickland (1960) k values for marine phytoplankters (mainly diatoms) are generally near the optimum and the results are rarely outside the range of 0.02 to 0.15 (hours)⁻¹. For example Braarud (1944) reported about 0.15 for

small diatoms decreasing to 0.07 to 0.05 for larger species. The values given by Smayda (1957) are near to 0.05 and Harvey (1934) suggested a value of 0.12 for Chaetoceros. For Phaeodactylum tricornutum k is approximately 0.06 (Ketchum 1939 a; Raymond and Adams, 1958). The generation time for Gymnodinium is 12 hours indicating a k around 0.06 (Ragotskie and Pomeroy, 1957). The t_g value for culture of Gonyaulax polyedra is nearly 2 days (Sweeney and Hastings, 1958). McLeod (1957) gives t_g as 12 hours for Dunaliella euchlora. For total phytoplankton population Harvey, et al. (1935) estimated k as about 0.035.

Table 7A to G give the k and t_g values for mixed populations of phytoplankton and a few common species of diatoms in the Gulf of Mannar, enclosed in light and dark bottles, along with experiments for measuring primary production. In both there was increase in numbers; but in the dark bottles as there was no addition of new material by photosynthesis (because of the continuous darkness) k values tend to be lower. But the populations exposed to the diurnal variations of light in the clear bottles would represent almost ^{those in} natural conditions.

The shortest generation time recorded was 5 hours for Thalassionema nitschiae representing a k value of 0.13. For the mixed population the shortest doubling time was 9 hours ($k = 0.08$). For Eurosigma and Navicula, the common

litteral forms occurring in the samples, the doubling time on the average is a little less than 24 hours - Table P and G. Lanskaya (1961) reported a three-hour doubling time ($k = 0.23$) is possible for Skeletonema and the time of division as early morning hours. It is likely that some of the k values given in the table would have been higher if the grazing effect had been eliminated by filtering off the zooplankters before incubation.

In coastal areas the nature of phytoplankton production is one of large blooms followed by periods of grazing and decay. The rate of increased productivity arises mainly from an increase of the standing crop and not of the growth constant k since k does not follow a seasonal pattern.

Table 7a. Growth kinetics of mixed population of phytoplankton and some selected species in light and dark bottles during a 48-hour period of incubation (in situ)

| Month | Light bottle | | | | dark bottle | | |
|-------|--------------|---------|-------|-------|-------------|-------|-------|
| | n_0 | n_t | k | t_k | n_t | k | t_k |
| Jan. | 8,770 | 85,400 | 0.047 | 15 | 15,400 | 0.017 | 41 |
| | 24,870 | 107,870 | 0.031 | 23 | 50,640 | 0.015 | 47 |
| | 14,610 | 54,880 | 0.028 | 25 | 23,120 | 0.010 | 70 |
| | 33,420 | 85,110 | 0.019 | 37 | 131,190 | 0.018 | 25 |
| | 51,180 | 119,190 | 0.018 | 39 | -- | -- | -- |

(Contd. Table 7a)

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|------|----------|-----------|-------|-----|----------|-------|-----|---|
| Feb. | 8,320 | 12,210 | 0.008 | 88 | 20,290 | 0.019 | 37 | |
| | 15,360 | 22,460 | 0.008 | 88 | 13,220 | - | - | |
| | 7,610 | 23,480 | 0.023 | 30 | 6,410 | - | - | |
| | 15,210 | 92,000 | 0.038 | 18 | 19,040 | 0.013 | 54 | |
| Mar. | 19,870 | 47,710 | 0.018 | 39 | 16,640 | - | - | |
| | 6,200 | 51,170 | 0.044 | 16 | 6,020 | - | - | |
| | 21,090 | 221,200 | 0.049 | 14 | 75,600 | 0.026 | 27 | |
| | 115,090 | 163,510 | 0.073 | 10 | 14,460 | - | - | |
| Apr. | 27,710 | 57,600 | 0.015 | 47 | 13,100 | - | - | |
| | 1510,000 | 5020,000 | 0.025 | 28 | 2016,000 | 0.006 | 117 | |
| | 159,000 | 476,000 | 0.023 | 31 | 160,000 | - | - | |
| | 1142,000 | 22024,000 | 0.062 | 11 | 112,000 | - | - | |
| May | 76,200 | 744,000 | 0.048 | 15 | 119,400 | 0.009 | 78 | |
| | 62,800 | 203,200 | 0.024 | 29 | 22,600 | - | - | |
| | 22,200 | 48,800 | 0.016 | 43 | 26,200 | 0.003 | 233 | |
| | 30,400 | 216,000 | 0.041 | 17 | 92,000 | 0.023 | 30 | |
| | 10,400 | 19,000 | 0.013 | 54 | 9,600 | - | - | |
| Jun. | 2,200 | 7,800 | 0.026 | 27 | 6,400 | 0.022 | 32 | |
| | 3,000 | 3,600 | 0.004 | 175 | 4,400 | 0.008 | 88 | |
| | 410 | 770 | 0.013 | 54 | -- | -- | -- | |
| Jul. | 640 | 2,050 | 0.024 | 29 | 1,450 | 0.017 | 41 | |
| | 1,870 | 31,800 | 0.059 | 12 | 4,150 | 0.017 | 41 | |
| | 280 | 2,104 | 0.042 | 17 | 650 | 0.018 | 39 | |
| Aug. | 100 | 1,330 | 0.054 | 13 | 910 | 0.046 | 15 | |
| | 670 | 1,520 | 0.017 | 41 | 540 | - | - | |
| | 510 | 1,790 | 0.026 | 27 | 1,130 | 0.017 | 41 | |

(Contd. Table 7a)

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|------|--------|---------|-------|----|---------|-------|----|---|
| Sep. | 350 | 690 | 0.014 | 50 | 950 | 0.021 | 33 | |
| | 1,280 | 14,490 | 0.051 | 14 | 6,320 | 0.033 | 21 | |
| | 4,190 | 12,310 | 0.023 | 31 | 1,100 | - | - | |
| Oct. | 150 | 1,840 | 0.052 | 13 | 2,300 | 0.057 | 12 | |
| | 6,600 | 323,950 | 0.081 | 9 | 107,700 | 0.058 | 12 | |
| | 3,380 | 5,060 | 0.008 | 8 | 1,530 | - | - | |
| | 150 | 1,840 | 0.052 | 13 | 2,300 | 0.057 | 12 | |
| Nov. | 61,480 | 237,560 | 0.028 | 25 | 33,640 | - | - | |
| | 34,540 | 253,600 | 0.042 | 17 | 40,000 | - | - | |
| | 12,730 | 151,660 | 0.052 | 13 | 61,510 | 0.033 | 21 | |
| Dec. | 22,940 | 123,730 | 0.035 | 20 | 34,640 | 0.009 | 78 | |
| | 16,980 | 98,210 | 0.037 | 19 | 33,040 | 0.014 | 50 | |
| | 24,030 | 51,980 | 0.016 | 44 | 24,570 | - | - | |
| | 20,630 | 48,180 | 0.018 | 39 | 14,360 | - | - | |

7b. Coccinedisca spp.

| Month | n ₀ | n _t | k | t _x |
|-------|----------------|----------------|-------|----------------|
| July | 72 | 155 | 0.016 | 44 |
| | 6 | 37 | 0.038 | 18 |
| Aug. | 10 | 30 | 0.023 | 30 |
| Sept. | 20 | 100 | 0.034 | 21 |
| Nov | 640 | 3,040 | 0.032 | 22 |
| | 1,600 | 4,500 | 0.022 | 32 |
| Dec. | 6,000 | 37,600 | 0.038 | 18 |
| | 4,000 | 13,000 | 0.020 | 35 |
| | 1,400 | 7,400 | 0.035 | 20 |
| | 1,600 | 4,800 | 0.023 | 30 |
| Jan | 200 | 1,600 | 0.043 | 16 |
| | 200 | 1,800 | 0.046 | 15 |
| | 400 | 1,400 | 0.026 | 27 |
| | 200 | 400 | 0.014 | 59 |

7a. Chaetoceros spp.

| | n_0 | n_t | k | t_K |
|------|-----------|------------|-------|-------|
| Apr. | 12,200 | 20,800 | 0.011 | 64 |
| | 1,480,000 | 5,000,000 | 0.025 | 28 |
| | 1,100,000 | 22,000,000 | 0.062 | 11 |
| | 70,000 | 700,000 | 0.048 | 15 |
| May | 51,000 | 1,900,000 | 0.075 | 9 |
| Dec. | 1,630 | 3,800 | 0.018 | 39 |
| Jan. | 5,200 | 20,000 | 0.028 | 25 |
| Oct. | 4,800 | 320,000 | 0.087 | 8 |
| Nov. | 560 | 1,420 | 0.019 | 37 |
| | 7,520 | 62,000 | 0.044 | 16 |
| | 3,200 | 22,400 | 0.041 | 17 |

7d. Thalassionema nitzschoides

| | n_0 | n_t | k | t_K |
|-------|--------|---------|-------|-------|
| July | 12 | 123 | 0.048 | 15 |
| Sept. | 30 | 350 | 0.051 | 14 |
| Nov. | 9,920 | 76,260 | 0.042 | 17 |
| | 4,000 | 90,000 | 0.065 | 11 |
| | 25,000 | 45,000 | 0.012 | 52 |
| Dec. | 900 | 4,960 | 0.036 | 19 |
| | 4,000 | 8,600 | 0.016 | 44 |
| | 40 | 25,400 | 0.534 | 5 |
| Apr. | 60 | 9,400 | 0.105 | 7 |
| May | 11,200 | 38,000 | 0.025 | 28 |
| | 13,000 | 100,000 | 0.043 | 16 |
| | 4,200 | 11,000 | 0.020 | 35 |
| Jun. | 300 | 4,200 | 0.049 | 14 |
| | 120 | 260 | 0.016 | 44 |

7e. Thallassiothrix frauenfeldii

| | n_o | n_t | k | t_k |
|------|-------|--------|-------|-------|
| Oct. | 70 | 350 | 0.022 | 32 |
| Nov. | 2,000 | 2,600 | 0.005 | 140 |
| | 2,000 | 20,000 | 0.048 | 15 |
| | 9,600 | 18,120 | 0.006 | 117 |
| | 900 | 4,960 | 0.036 | 19 |
| Dec. | 800 | 4,000 | 0.034 | 21 |
| | 110 | 4,000 | 0.075 | 9 |
| | 2,200 | 4,000 | 0.012 | 58 |
| | 40 | 2,800 | 0.089 | 8 |
| | 800 | 5,200 | 0.039 | 18 |
| | 30 | 800 | 0.068 | 10 |
| May | 2,000 | 5,000 | 0.019 | 37 |
| | 6,200 | 16,000 | 0.020 | 35 |
| | 1,600 | 2,600 | 0.010 | 70 |

7f. Pleurosigma spp.

| | n_o | n_t | k | t_k | k | t_k |
|------|--------|--------|-------|-------|-------|-------|
| Jan. | 2,000 | 22,000 | 0.051 | 14 | | |
| | 5,400 | 33,200 | 0.038 | 18 | | |
| | 10,000 | 60,000 | 0.037 | 19 | | |
| | 10,200 | 75,400 | 0.042 | 17 | 0.042 | 17 |
| Feb. | 3,400 | 15,200 | 0.031 | 22 | | |
| | 4,200 | 13,600 | 0.025 | 28 | | |
| | 6,200 | 34,600 | 0.028 | 25 | 0.028 | 25 |

(Contd. Table 7f)

| | n_o | n_t | k | t_g | k | t_g |
|------|-------|---------|-------|-------|-------|-------|
| Mar. | 5,200 | 17,000 | 0.022 | 28 | | |
| | 3,000 | 26,600 | 0.046 | 15 | | |
| | 8,400 | 63,200 | 0.042 | 17 | | |
| | 4,200 | 204,000 | 0.081 | 9 | 0.048 | 19 |
| Nov. | 190 | 2,710 | 0.055 | 13 | | |
| | 2,720 | 11,360 | 0.030 | 23 | | |
| | 480 | 9,120 | 0.061 | 11 | | |
| | 880 | 2,400 | 0.021 | 34 | 0.042 | 20 |
| Dec. | 2,100 | 7,200 | 0.026 | 27 | | |
| | 1,200 | 14,000 | 0.051 | 14 | | |
| | 1,800 | 5,800 | 0.024 | 29 | | |
| | 1,600 | 4,800 | 0.044 | 16 | | |
| | 2,600 | 4,000 | 0.009 | 78 | 0.031 | 33 |

7g. Navicula spp

| n_o | n_t | k | t_g |
|---------|-------|-------|-------|
| 320 | 3,500 | 0.050 | |
| 280 | 800 | 0.022 | |
| 400 | 1,120 | 0.021 | |
| 1,120 | 6,400 | 0.036 | |
| 2,000 | 8,400 | 0.030 | |
| 1,800 | 5,600 | 0.024 | |
| 800 | 8,000 | 0.048 | |
| Average | | 0.033 | 21 |

Growth and productivity characteristics of a green
Flagellate, *PETRASTRUM FRAGILLIS* Kylin.

It has been pointed out by Braarud (1961) that although studies on primary production in the sea by ^{14}C method have given valuable results, the problems related to the actual behaviour of the species which are responsible for the observed production have not been investigated. Ever since the classic work on diatom cultures by Marshall and Orr (1928) and Jenkin (1937) there have been several attempts to study the influence of such environmental factors as salinity, temperature, light and inorganic nutrients on the growth and photosynthesis of phytoplankters. In addition, there have been a number of kinetic studies on unicellular algae in culture (cf. Strickland, 1960). It is also possible to find answers to the many problems facing the field ecologist in the microcosm of the culture flask. For example, the phenomenon of succession in the Gochin backwater has been found to be due to the varying nutrient requirement of the different phytoplankters (Qasim, 1973).

Unicellular algae grown in culture show a variable lag interval, succeeded by a vigorous logarithmic growth phase, culminating in the cessation of growth brought about by nutrient depletion or by metabolites which inhibit further growth

(Kain and Fogg, 1958). This study of such a growing culture of Tetraselmis gracilis from the period inoculation for over a month gives the growth trend and productivity characteristics and also the comparative values obtained by oxygen and ^{14}C methods.

Tetraselmis gracilis, a commonly occurring flagellate in the coastal waters of Cochin is an unicellular green and phototactic flagellate with an oval shape, having a diameter of 6μ . Reproduction takes place by longitudinal fission of the protoplasts into two daughter cells. Their phototactic behaviour was found useful for their isolation, and they were cultured in Miquel's ^{medium} (modified by Ketchum and Refield, 1958).

One week old healthy and synchronous culture of 4 ml (all motile) having a concentration of 150,000 cells/ml were inoculated into 3 litres of the medium taken in 5 litre conical flasks and grown in diffused daylight at room temperature, under aeration. Aliquots of the culture were taken every alternate day and determinations were made of chlorophylls a and b by the method of Parsons and Strickland (1963) using a Unicam Spectrophotometer. The carbon production was measured by the oxygen and ^{14}C techniques. The experimental time was 3 hours at 20 klux. Activity of filter was determined on a Geiger Counting System (Electronics Corporation of India)

having a counting efficiency of 3.2%. The growth parameters were measured for over a month totalling twenty seven observations (Table 8).

Growth trend in Tetraselmis:

From an initial concentration of 200 cells/ml it increased to 1000 cells/ml by the second day and then to 30,000 cells/ml on the third day. By the fifth day, the concentration reached 100,000 cells/ml. The exponential growth phase reached its climax by the seventh day when the concentration was 330,000 cells/ml.

The highest k value of 0.05 was obtained on the fifth day when the mean generation time, t_g , was 14 hours. From then on there was a steady decrease in the k value and a progressive increase in the mean generation time, t_g . The k value dropped to 0.01 by the twenty fifth day and thereafter continued at this level till the thirty fifth day. The generation time, t_g , meanwhile increased to 70 hours. Though the cell number/ml exceeded 1 million by the end of this period, the decrease of the k value and the increase in the t_g suggest that the cells were no longer actively dividing due to nutrient deficiency. Ketchum (1939b) has shown that phosphorus becomes a limiting factor in dense cultures of Nitzschia closterium. Repeated additions of nutrients could prolong the exponential phase of growth in cultures, as shown by Rayment and Adams (1958).

The t_g value for a similar chlorophycean flagellate Dunaliella euklora is 12 hours (McLeod, 1957). Wood (1958) remarks that in tropical forms k values will be higher than that in temperate forms, but such variation is not observed in this species.

Chlorophylls in relation to production:

In Chlorophycean algae chlorophyll a forms a major pigment and b forms only a minor component. As the chlorophyll content is an index of the photosynthetic potential, and its increase represents the multiplication and growth of the alga, simultaneous measurements of cell counts and chlorophylls a and b were measured. Chlorophyll a values showed a progressive increase from 550 $\mu\text{g/l}$ representing a concentration of 33×10^4 cells. The maximum value obtained by the end of the month was 3116 $\mu\text{g/l}$ representing 1×10^6 cells. Chlorophyll a per unit of 1000 cells thus indicate an increase from $< 2 \mu\text{g}$ to $> 3 \mu\text{g}$. This increase with the growth of the culture may be due to chlorophyll released by rapture of older cells.

Several estimates in phytoplankton have been made of the number of cells that contain unit weight of chlorophyll. No average figure has any significance. Strickland (1960) gives the following expression:

$$\text{No. of cells} = P \times 10^6 \times \text{mg chlorophyll}$$

Accordingly the value for F in Tetraselmis in the initial period of growth is 0.6 which decreases with the age of the culture. If chlorophyll a and b are together considered F is 0.4.

The variation in values ^{of} chlorophyll b per litre ranged from about 300 $\mu\text{g}/$ representing 35×10^4 cells to 11000 μg for 1×10^6 cells. The mean value for 1000 cells of chlorophyll b is 1.1 μg . The ratio of chlorophyll a to b was uniformly constant from the end of the first week (when measurements of pigments were commenced) to the end of the experiment.

In nature, the concentration of chlorophyll, per unit volume of water for the upper part of the euphotic zone, varies throughout the day more or less in accordance with the variation in the rate of potential photosynthesis. This phenomenon is observed even in bodies of water enclosed in transparent plastic bags (Yentsch and Ryther, 1957). In the experimental culture light was fairly constant without marked diel variation (about 3-4 klux). Hence the variation in the chlorophyll concentration can be fully attributed to the multiplication, growth and subsequent decline of the cells.

The gross carbon values per litre per hour ranged from 0.07 to 0.79 mgC measured by the oxygen technique, and from

0.03 to 0.34 mgO per hour by ^{14}C technique. When the production rate per unit number of cells (1000) was calculated from the oxygen change, the highest rate observed was during the exponential phase and thereafter decreased steadily. This confirms the earlier observation that the increase of chlorophylls in the culture per unit volume as well as per unit number of cells represent some of the liberated chlorophylls which are no longer photosynthetically active.

The ^{14}C technique registered lower values constantly in all the observations (Table 8), being generally 50% or even less. The difference may be the cumulative effect of the various factors such as: nutrient depletion, a higher PQ of the culture, secretion of labelled carbohydrate in dissolved form, or the rupture of the fragile membrane during filtration. Due to such large differences ^{14}C values may not reflect the real production in measurements with Tetraselmis.

The gross and net production values given in Table 8 were computed using the formula given by Steemann Nielsen (1964). The respiration rate has been observed to be about 50%. By extrapolation of the curve showing the rate of net photosynthesis as a function of light intensity, as given by Steemann Nielsen and Hansen (1959), the rate of respiration deduced was 36% (Fig. 24).

Thus it would appear that some of the discrepancy in the oxygen and ^{14}C values is brought about ^{by} the inherent

nature of the constituent organisms in the population. When fragile flagellates dominate in the plankton ^{14}C measurements would naturally record lower values and an arbitrary correction of 10% for respiration would not be adequate to compute gross production.

Table 8. Daily variations in cell numbers, chlorophylls and rate of primary production

| Age in days | Cells/ml | Chlorophyll concentration | | | Production | | | | |
|-------------------|----------|---|----------|------------|---|---------------|---------------------------------------|-----------------------------|------|
| | | <u>a</u> ($\mu\text{g}/1000$ cells) | <u>b</u> | <u>a:b</u> | Oxygen method | | ^{14}C method | | |
| | | | | | gross net per $\text{mgO}/\text{l/hr}$ | 1000 cells | gross net $\text{mgC}/\text{l/hr}$ | / $\mu\text{g}/\text{l/hr}$ | |
| 0 | 200 | -- | -- | -- | -- | -- | -- | -- | -- |
| 2 | 1000 | -- | -- | -- | -- | -- | -- | -- | -- |
| 3 | 30000 | -- | -- | -- | 0.07 | 0.03 | 2.4 | 0.03 | 0.02 |
| 4 | 40000 | -- | -- | -- | -- | -- | -- | -- | -- |
| 5 | 100000 | -- | -- | -- | 0.23 | 0.15 | 2.27 | 0.06 | 0.06 |
| 7 | 330000 | 1.66 | 0.82 | 2.3:1 | 0.31 | 0.24 | 0.93 | 0.14 | 0.13 |
| 8 | 280000 | -- | -- | -- | -- | -- | -- | -- | -- |
| 9 | 370000 | 2.08 | 0.88 | 2.3:1 | -- | -- | -- | 0.22 | 0.20 |
| 10 | 390000 | 2.15 | 0.89 | 2.3:1 | 0.41 | 0.35 | 1.04 | 0.19 | 0.17 |
| 11 | 410000 | 2.61 | 1.08 | 2.3:1 | 0.52 | 0.41 | 1.26 | 0.20 | 0.18 |
| 14 | 440000 | 3.09 | 1.48 | 2.3:1 | 0.62 | 0.46 | 1.42 | 0.28 | 0.25 |
| 15 | 490000 | 3.12 | 1.08 | 2.3:1 | 0.46 | 0.39 | 0.94 | 0.22 | 0.20 |
| 16 | 520000 | -- | -- | -- | -- | -- | -- | -- | -- |
| 17 | 600000 | 2.28 | 1.03 | 2.3:1 | 0.46 | 0.36 | 0.77 | -- | -- |
| 18 | 740000 | -- | -- | -- | -- | -- | -- | -- | -- |
| 19 | 760000 | 2.63 | 0.85 | 4:1 | 0.54 | 0.44 | 0.71 | 0.34 | 0.30 |
| 21 | 770000 | 2.91 | 1.03 | 2.3:1 | 0.79 | 0.60 | 1.02 | 0.15 | 0.13 |
| 22 | 730000 | -- | -- | -- | -- | -- | -- | -- | -- |
| 23 | 730000 | 3.18 | 1.26 | 2.3:1 | 0.71 | 0.57 | 0.97 | 0.20 | 0.18 |
| 24 | 730000 | -- | -- | -- | -- | -- | -- | -- | -- |
| 25 | 730000 | 3.24 | 1.28 | 2.3:1 | 0.18 | 0.10 | 0.25 | 0.09 | 0.08 |
| 28 | 800000 | 3.24 | 1.32 | 2.3:1 | 0.25 | 0.19 | 0.32 | 0.18 | 0.16 |
| 30 | 900000 | 3.35 | 1.32 | 2.3:1 | 0.60 | 0.40 | 0.66 | 0.13 | 0.12 |
| 31 | 1030000 | -- | -- | -- | -- | -- | -- | -- | -- |
| 32 | 1070000 | 2.91 | 1.03 | 2.3:1 | 0.66 | -- | 0.61 | 0.17 | 0.15 |
| 33 | 1070000 | -- | -- | -- | -- | -- | -- | -- | -- |
| 35 | 970000 | 3.21 | 1.08 | 2.3:1 | 0.64 | -- | 0.66 | 0.26 | 0.24 |

SEASONAL AND REGIONAL VARIATION IN PRIMARY PRODUCTION IN THE INDIAN SEAS

Out of the 307 million hectares of shallow water areas in the Indian Ocean 40 million hectares are continuous to the coast line of India. Of this about 17.5 million hectares are within 50 m depth contour and the rest between 50 and 200 m. The major pelagic and demersal fishery resources are taken at present within the 50 m depth and as such the productivity of these areas is of immediate interest. The west coast of India has a broader shelf and so 11.5 million hectares of shallow (< 50 m depth) area are on the west coast and 6 million hectares on the east coast. Inspite of some variability due to seasonal fluctuation this area, in general, is very productive as may be seen from the following account.

Gulf of Mannar:

The magnitude of production and seasonal variation have been computed mainly from light and dark bottle experiments. The daily gross production per unit volume of water was separately calculated for surface and bottom (For most part of the year the entire column is within the euphotic zone). The consumption was calculated by the decrease in the dark bottle and net community production by deducting the respiration from the gross and also by the net increase in the

light bottles. The daily values were integrated to obtain the production per unit area per day and by multiplying the average daily values by the number of days per month total monthly production was obtained. From that the annual production was computed.

Table 9. Variation in average values (per unit volumes) of gross production, consumption and net community production as gross minus respiration (1) and net increase in light bottle (2), at Station 61.

| Period | Gross production | Consumption | Net community production | | |
|-----------|--------------------------|-------------------------|---------------------------|-------|---|
| | mg C/m ³ /day | mgC/m ³ /day | (mgC/m ³ /day) | 1 | 2 |
| January | 280.0 | 45.6 | 234.4 | 233.3 | |
| February | 203.7 | 61.8 | 141.9 | 141.9 | |
| March | 254.5 | 141.3 | 113.2 | 102.1 | |
| April | 324.7 | 128.1 | 196.6 | 196.3 | |
| May | 370.4 | 177.1 | 193.3 | 198.3 | |
| June | 117.7 | 95.1 | 22.6 | 22.5 | |
| July | 77.4 | 49.5 | 27.9 | 27.9 | |
| August | 95.7 | 41.4 | 54.3 | 45.7 | |
| September | 127.4 | 127.4 | 00.0 | 54.0 | |
| October | 236.5 | 86.5 | 50.0 | 55.1 | |
| November | 171.5 | 60.7 | 110.8 | 111.0 | |
| December | 240.6 | 66.6 | 174.0 | 234.3 | |

Annual gross production per unit volume = 72.10 gC/m^3
 " consumption " = 32.92 " (45.6%)
 Annual community production " = 39.18 "

Table 10. Average annual production per square metre of the sea surface for the respective stations

| Station | 1958 | 1959 | 1960 | 1961 |
|---------|------|------|------|------|
| G1 | 361 | 379 | 399 | - |
| G2 | - | 103 | 100 | 142 |
| G3 | - | 341 | 387 | 797 |
| G4 | - | 261 | 200 | 176 |
| G5 | - | 344 | 488 | 729 |
| G6 | - | 594 | 544 | 641 |

At station G1, there were two peaks of production - one in April-May and the other in the latter part of the year. During the first year of the study the mean monthly values ranged from $77 \text{ mgC/m}^3/\text{day}$ in July to $350 \text{ mgC/m}^3/\text{day}$ in May with an average of about $200 \text{ mgC/m}^3/\text{day}$. In the second year the values for the corresponding period were $124 \text{ mgC/m}^3/\text{day}$ in July and $388 \text{ mgC/m}^3/\text{day}$ in April. The values for the surface and bottom were more or less of the same order of magnitude. The annual gross production for Station G1 at the surface was 72.10 gC/m^3 and consumption

32.92 gC/m³ leaving an annual net community production of 39.18 gC/m³. The total consumption amounted to 45.6% of the gross production (Table 9).

The column production for station G1 ranged from 1.85 gC/m²/day in May to 0.39 gC/m²/day in June. The annual production for the three years of study were 361, 379 and 399 gC/m². (Table 10). Station G2 showed a comparatively lower rate whereas G5 and G6 had a higher rate. The mean value for all the 6 stations for the three years of complete observation was 400 gC/m²/year.

¹⁴C experiments were conducted only at random along with oxygen experiments. In all the experiments conducted in the shallow waters rates of production at the surface were higher than at the bottom (297 to 438 mg/m³/day at the surface). But at a deep water station off Tuticarin, where the euphotic zone extends to 45 metres, the maximum rate per unit volume was at 10 metres - 372 mgC/m³/day (Fig.20). The column production at this station in August, which was not particularly a period of high production, amounted to 6.8 gC/m²/day.

Dark uptake was 1% at the surface and 2% at the bottom. Rate of production in samples taken at noon and incubated till sunset was only one-fourth of that taken at sunrise for the surface samples, but was nearly the

same for the bottom samples. Though there has been a marked depression thus at noon, the afternoon samples registered a steep rise. In this connection it has been pointed out by Strickland (1965) that observations in the Pacific at 50°N have indicated that the best approximation to the daily rate is given by twice the photosynthesis measured in one experiment lasting from dawn to solar noon. Twice the value from mid-day to dusk is markedly lower and the worst results are obtained from a full day of incubation or from extrapolations of experiments of short duration made in the morning or afternoon.

Falk Bay:

^{14}C experiments were conducted in Falk Bay from 1961 to 1964 at different stations (P1-P6) at different periods. The values integrated for depth ranges of 8, 10 and 12 metres depending on the station of observation are pooled and given in Table.11.

Table ii. Rate of production per unit volume at different depths and per unit area of sea surface in Falk Bay.

| Date | Station | Depth in m | Production $\text{gC/m}^2/\text{day}$ | |
|-----------|----------------|------------|---------------------------------------|-----------------------------|
| | | | $\text{mgC/m}^3/\text{day}$ | $\text{mgC/m}^2/\text{day}$ |
| 13-3-1961 | P ₂ | 0 | 36.5 | |
| | | 5 | 40.5 | |
| | | 10 | 53.3 | 0.4 |

(Contd Table 11)

| 1 | 2 | 3 | 4 | 5 |
|-----------|---------------------------------------|----|--------|-----|
| 12-6-1961 | P_2 | 0 | 638.0 | |
| | | 5 | 489.0 | |
| | | 10 | 143.0 | 4.4 |
| 26-6-1962 | P_2 | 0 | 1061.5 | |
| | | 10 | 153.2 | 6.0 |
| | | 5 | 2341.9 | |
| 4-7-1962 | P_2 | 0 | 545.0 | |
| | | 10 | 52.5 | 8.7 |
| | | 5 | 1375.2 | |
| 9-7-1962 | P_2 | 0 | 53.3 | |
| | | 10 | 37.5 | 3.8 |
| | | 5 | 774.3 | |
| 11-7-1962 | P_6 | 0 | 147.2 | |
| | | 5 | 8.9 | 3.2 |
| | | 12 | | |
| 18-7-1962 | P_4 | 0 | 543.2 | |
| | | 6 | 250.9 | |
| | | 12 | 38.7 | 3.2 |
| 20-2-1963 | $9^{\circ}24'N$, $79^{\circ}13'E$ | 0 | 20.4 | |
| | | 5 | 10.2 | |
| | | 10 | 1.8 | 0.1 |
| 21-2-1963 | $9^{\circ}44'N$, $79^{\circ}16'E$ | 0 | 42.2 | |
| | | 5 | 12.4 | |
| | | 10 | 2.6 | 0.2 |
| 11-6-1963 | P_2 | 0 | 129.1 | |
| | | 4 | 135.2 | |
| | | 8 | 104.1 | |
| | | 10 | 4.9 | 1.0 |

(Contd. Table 11)

| 1 | 2 | 3 | 4 | 5 |
|------------|----------------|-----|--------|------|
| 17-6-1963 | P ₂ | 0 | 203.2 | |
| | | 4 | 320.4 | |
| | | 8 | 149.8 | |
| | | 10 | 62.4 | 2.2 |
| 26-8-1964 | P ₁ | 0 | 288.5 | |
| | | 4 | 165.1 | |
| | | 8 | 78.9 | 1.4 |
| 26-8-1964 | P ₁ | 0 | 341.9 | |
| | | 8 | 77.7 | 1.68 |
| 2-9-1964 | P ₁ | 0 | 156.9 | |
| | | 8 | 119.9 | 1.11 |
| -10- | P ₂ | 0 | 144.8 | |
| | | 8 | 112.5 | 1.03 |
| 16-9-1964 | P ₁ | 0 | 166.0 | |
| | | 8 | 88.7 | 1.02 |
| 9-10-1964 | P ₂ | 0 | 170.0 | |
| | | 5 | 155.3 | |
| | | 10 | 37.9 | 1.30 |
| 13-10-1964 | P ₁ | 0 | 157.0 | |
| | | 3.5 | 106.6 | |
| | | 7 | 52.4 | 0.74 |
| 19-10-1964 | P ₂ | 0 | 181.2 | |
| | | 5 | 146.8 | |
| | | 10 | 44.4 | 1.29 |
| | | 0 | 1.4 | |
| 22-10-1964 | P ₂ | 0 | 225.84 | |
| | | 5 | 151.20 | |
| | | 10 | 37.32 | 1.41 |

**Table 12. Mean integrated values of Primary production
in Palk Bay per unit area (i - interpolated
values)**

| <u>Month</u> | <u>Production gJ/m²/day</u> |
|--------------|--|
| January | 0.45 (i) |
| February | 0.15 |
| March | 0.40 |
| April | 1.40 (i) |
| May | 2.40 (i) |
| June | 3.40 |
| July | 4.70 |
| August | 1.54 |
| September | 1.05 |
| October | 1.19 |
| November | 0.95 (i) |
| December | 0.70 (i) |

Annual gross production
- 561 gC/m²

For the months when data are not available interpolated values have been taken (Table -12).

From the low rate of $< 0.5 \text{ gC/m}^2/\text{day}$ during January-March, the rate of primary production steadily rises to $4.7 \text{ gC/m}^2/\text{day}$ in July. From ^{then} the rate drops ^{to} $1.5 \text{ gC/m}^2/\text{day}$ by August and continues at a steady rate of $1 \text{ gC/m}^2/\text{day}$ till the month of December. Thus the primary production in Palk Bay is conspicuous with a single peak in July and more or less maintain a high rate of $> 1.0 \text{ gC/m}^2/\text{day}$ from April to October. The annual production is computed at 561 gC/m^2 which makes the region comparatively richer than all the inshore environment studied in the Indian seas.

Palk Bay being a sheltered area with a larger autochthonous stock of phytoplankton, higher level of nutrients and better light penetration could sustain a high rate for a comparatively longer period. The period of low production coincides with the period of north-east monsoon when the sea is rough.

It is also noteworthy that during the period of intense phytoplankton production in July the surface production reached an exceptionally high value of $2340 \text{ mgC/m}^3/\text{day}$. Rate of production fell rapidly within 5 metres but there was appreciable production even at 10 metres. The column production

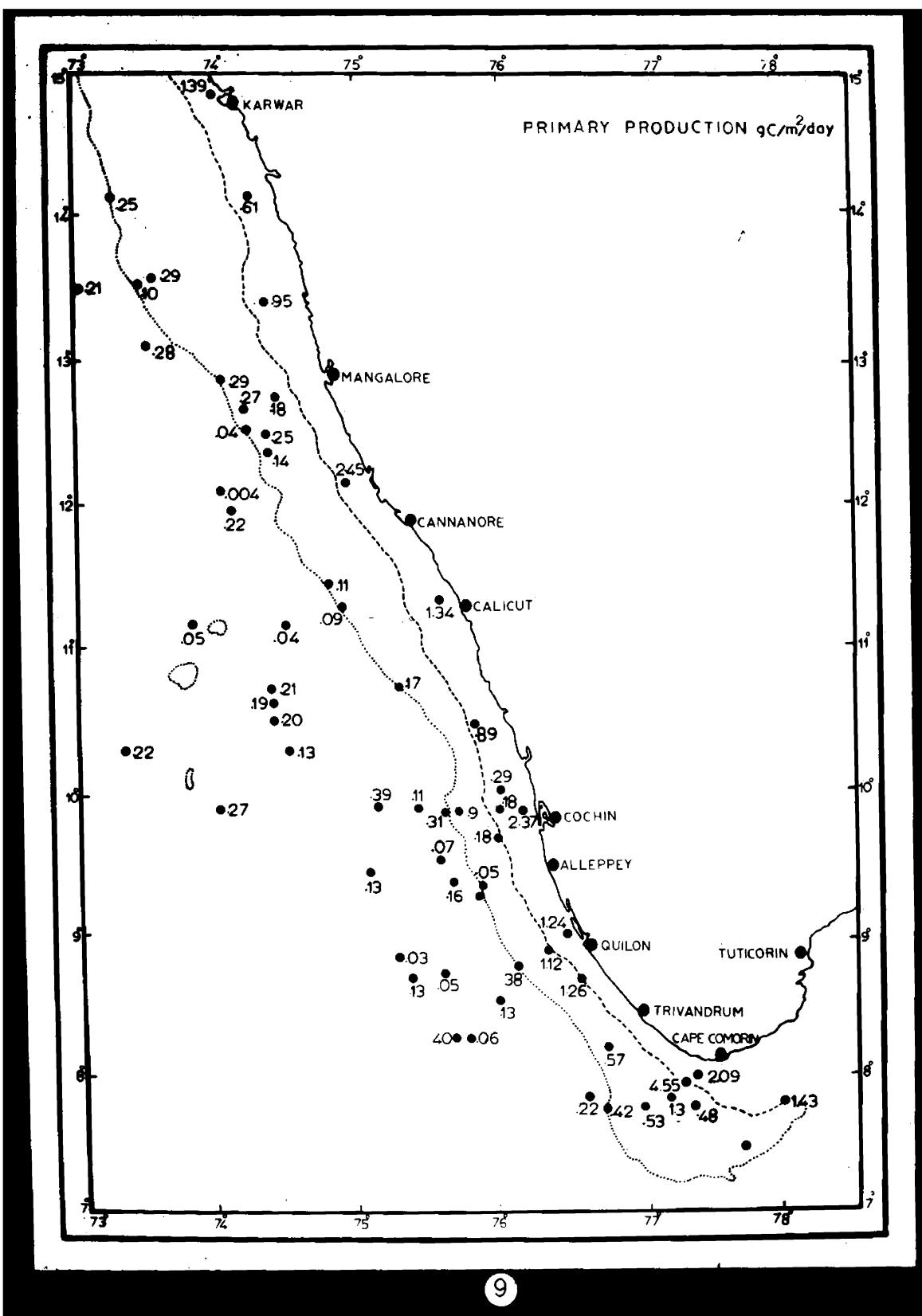
is usually between 3 to 6 $\text{gC/m}^2/\text{day}$ and once even attained the highest figure of $8.68 \text{ gC/m}^2/\text{day}$, which seems to be the highest rate ever recorded from anywhere in the Indian Ocean region.

In Walvis Bay, though Steemann Nielsen and Aabye Jensen (1957) observed a record production of $6600 \text{ mgC/m}^3/\text{day}$ in the surface waters due to the presence of a huge amount of naked dinoflagellate, the column production amounted to $3.8 \text{ gC/m}^2/\text{day}$ as the euphotic zone was only 0.8 metre deep. The maximum value recorded from the Arabian Sea was $6.4 \text{ gC/m}^2/\text{day}$ off the coast of Saudi Arabia Ryther *et al.* (1966).

South-west coast of India and the Laccadive Sea (Fig.9)

In the inshore areas on the south-west coast of India values over $2 \text{ gC/m}^2/\text{day}$ are obtained within 50 m depth during monsoon period. Over the Wedge Bank off the southern tip of the Peninsula, at a station 38 m deep, the production rate was $2.09 \text{ gC/m}^2/\text{day}$ in June. Just below the surface the rate per unit volume was $12 \text{ mgC/m}^3/\text{hour}$, suggesting a constant replenishment of nutrients. By using artificial light of about 20 klux rates as high as $52 \text{ mgC/m}^3/\text{hour}$ have also been observed with surface water during monsoon period at a station south of Mangalore ($12^{\circ}08'N$). The

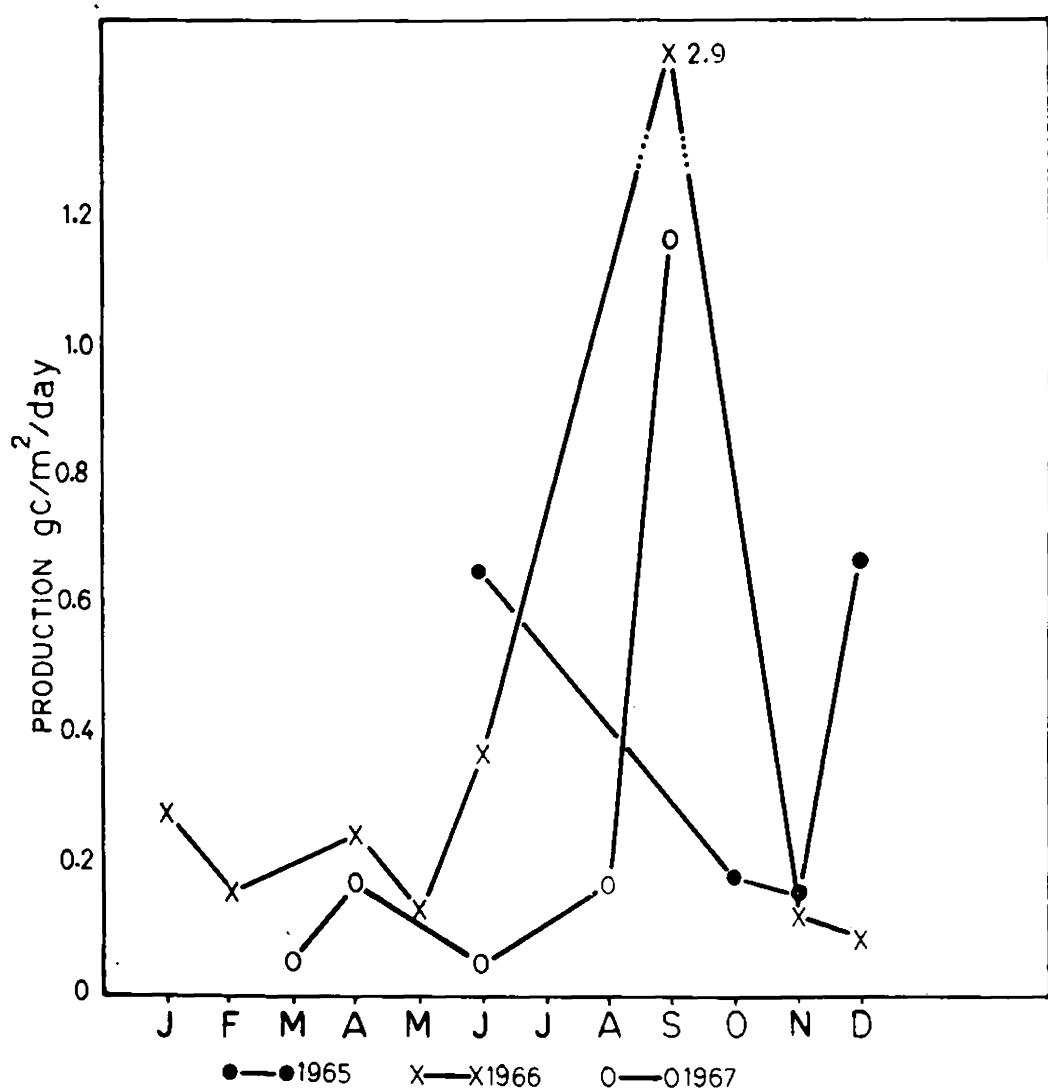
Fig.9. Stations occupied on the south-west coast of India and the Laccadive Sea during 1965-68 with the daily rates of primary production for the water column.



Highest value of $4.55 \text{ gC/m}^2/\text{day}$ for the west coast was observed at a station on the Vadge Bank in September. The mean monthly values for the three-years are shown in Fig. 10.

Though this rate of production is high it is not unusual for the shelf areas of the Indian Ocean. During the cruise of ANTON BRUEHL, values exceeding $1 \text{ gC/m}^2/\text{day}$ were observed at 8 stations of which three stations had values exceeding $3 \text{ gC/m}^2/\text{day}$. Radhakrishna (1969) observed in the shelf waters off Alleppey on the west coast during the post-monsoon period values ranging from $0.38 \text{ gC/m}^2/\text{day}$ to $1.11 \text{ gC/m}^2/\text{day}$ with an average of $0.81 \text{ gC/m}^2/\text{day}$. Cushing (1971) also points out Kabanova's observation about intense production off the Malabar coast, which extended seawards for a considerable distance. The observations of Subramanyam (1959) from standing crop measurements also confirm the high productivity of the inshore regions of the south west coast. The data presented in Table 13 and the summary of values for the different depth zones (Table 14) indicate that the level of organic production is high towards the coast, becomes less towards the edge of the continental shelf and is least outside the shelf, except in regions of deep water ascent (Kabanova, 1961) and around

Fig.10. The seasonal variation in values of primary production on the west coast based on monthly averages.



the Laccadive Islands (Prasad and Nair, 1962). Based on the observations made so far the annual gross production for the inshore region within 50 metres depth comprising a total area of 4,14,520 square kilometres has been computed as 50×10^6 tons of carbon.

For the zone between 50 m depth and the edge of the continental shelf the average rate is $0.47 \text{ gC/m}^2/\text{day}$ which is moderately high. The annual gross production would amount to 170 gC/m^2 and for 1,68,790 sq.km. of the shelf area between 50 and 200 metres the total production has been computed as 30×10^6 tons.

Table 13. Mean monthly production on the west coast of India within 50 m depth and the annual gross production computed from weighted averages.

| Month | rate of production $\text{gC/m}^2/\text{day}$ | Annual production |
|-----------|--|--|
| | | (gross) $\text{gC/m}^2/\text{year}$ |
| January | 0.29 | |
| February | 0.18 | |
| March | 0.13 | |
| April | 0.72* | |
| May | 1.40* | |
| June | 2.09 | |
| July | 1.45 | |
| August | 0.61 | |
| September | 1.46 | |
| October | 1.36* | |
| November | 1.22* | |
| December | 1.06 | 453 |

*Interpolated values

Table 14. Summary of primary production values on the west coast for the different depth zones in $\text{gC/m}^2/\text{day}$ and $\text{gC/m}^2/\text{year}$.

| No. of stns. | Up to 50 m | | 50 to 200 m | | > 200 m | | | | | | |
|--------------|--------------------|--------------|--------------------|--------------|--------------|--------------|--------------------|----------------|------|------|----|
| | Total no. of stns. | Ave- rage | Total no. of stns. | Ave- rage | No. of stns. | Ave- rage | Total no. of stns. | Ave- verage | | | |
| 23 | 28.47 | 1.24 | 453 | 23 | 10.91 | 0.47 | 172 | 41 | 7.21 | 0.18 | 66 |

Mud Bank at Alleppey:

During the south-west monsoon, along the southern section of the west coast of India, there is the periodic formation of mud banks known in local parlance as 'Chakara'. This heralds a spell of hectic activity to thousands of fisherfolk, who are otherwise kept away from their occupation by the cheddy monsoon seas. The areas of mud banks provide safe operation for the boats in an otherwise surf-ridden coast and yield a bountiful harvest of oil sardine and the highly priced prawns. In view of the impact that the mud banks make on the economy of the fishing community, the Central Marine Fisheries Research Institute initiated a concerted study in June 1971 to augment the meagre data available regarding their ecology and productivity. This account of primary production and related properties of the Alleppey mud bank forms part of it.

The most important and well-known mud banks are at Marakkal, just north of Cochin, off Alleppey and two smaller banks at or near Calicut (Kozhikode). The mud

banks at Calicut and Alleppey are of a shifting type. The earlier accounts on the mud banks are those of Bristow (1958), Dasmann et al. (1958), Seshappa (1953), Seshappa and Jayaraman (1956), Damodaran and Hridayanathan (1966), Hair et al. (1966), Rao (1967), Varma and Murup (1969). But none of these authors has dealt with the productivity.

Fortnightly or monthly collections of water samples from the surface and bottom were incubated with 5 μ ec of $\text{Na}_2^{14}\text{CO}_3$ under constant light of 20 klux and the potential productivity was determined which was converted into the daily rate of primary production as given before. The results are presented in Figs. 11 and 12 for the surface and bottom samples for the four stations. Total phytoplankton counts taken after settling the samples and chlorophyll measurements are given in Table 15.

The results show that there is a great amount of seasonal and spatial variability even within a limited area, which is not in consonance with the rate for the west coast as a whole. This is probably because of the special conditions existing in this environment especially during the season of the mud bank, which is between June to September. At this time the fine mud present in the area is churned up giving an oily appearance to the water and also releasing a considerable quantity of the nutrients.

Fig.11. The rates of potential productivity derived from tank experiments using the surface water of the mud bank. I to IV are for the respective stations of observation.

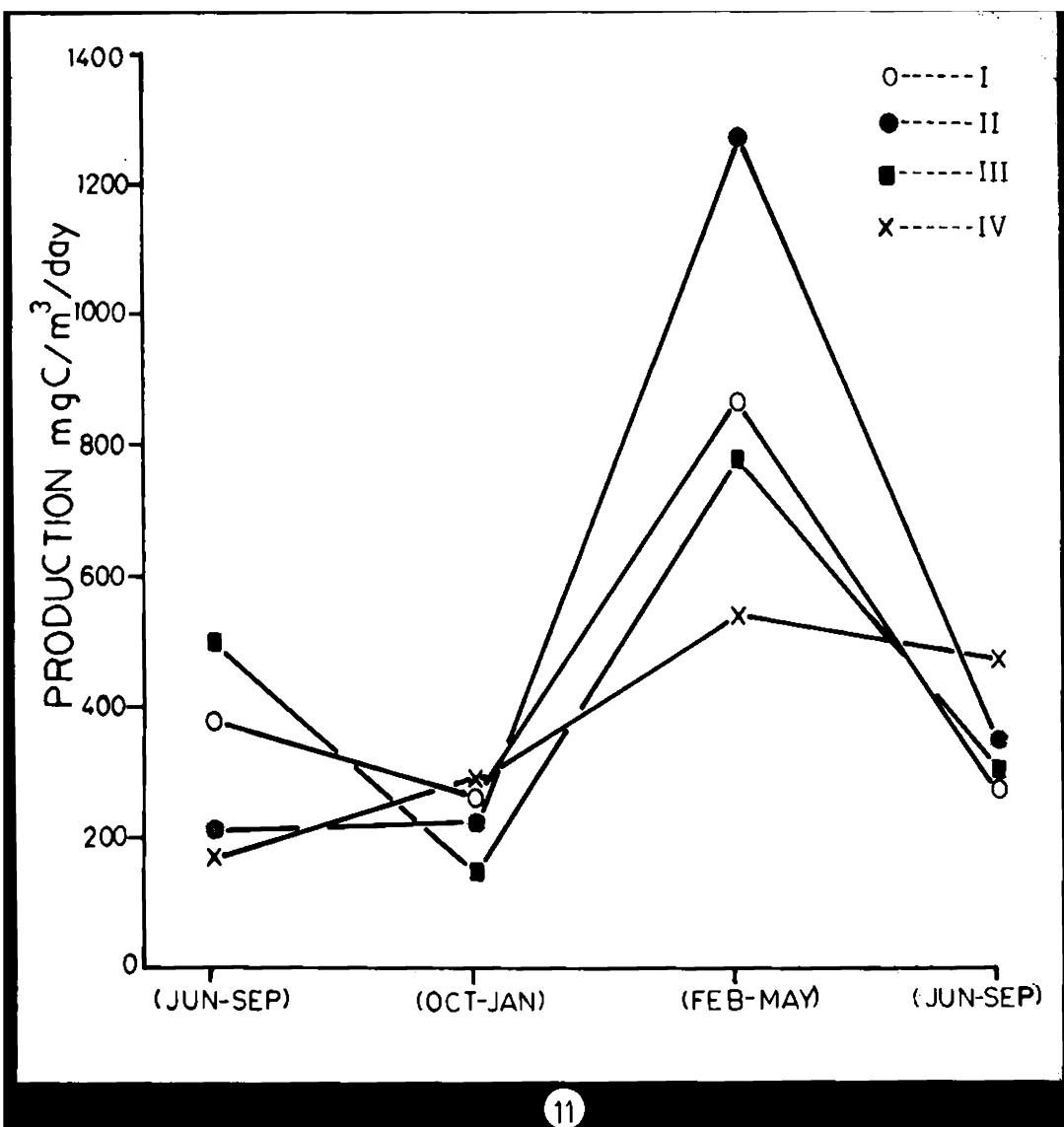
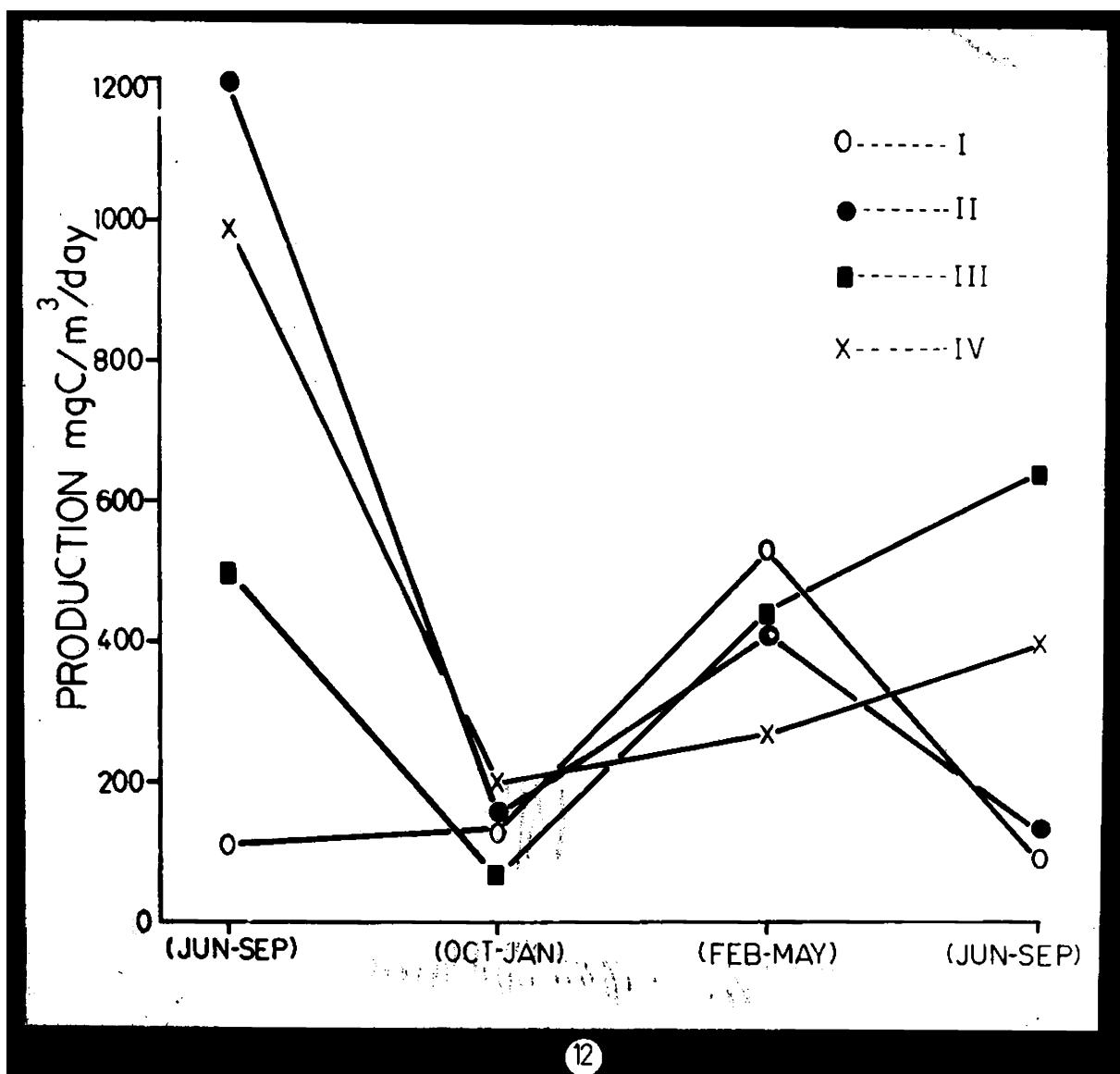


Fig.12. The rates of potential productivity derived from tank experiments using the water from the bottom of the mud bank area. I to IV are for the respective stations of observation. Grouping of data as in surface samples (Fig.11).



So the turbidity is very high allowing light penetration to less than a metre during the south-west monsoon period. The highest chlorophyll a values are observed during the June-September period. The potential productivity is lower for the surface samples as compared to the bottom samples. It is likely that the chlorophyll values do not represent a true index of standing crop in view of the presence of non-living chlorophyll released from the mud by wind and wave action. Low assimilation ratios (mgC/hr/mg chl a), except during February-May when stable conditions prevail, also indicate this fact (Table -15).

The total cell counts during the monsoon season are considerably influenced by the presence of Noctiluca, both the pink and green forms. The phenomenon of discoloured water caused by pink Noctiluca during June-September period along the west coast has been observed by Subrahmanyam (1959).

As may be seen from Table 15 the rate of potential assimilation is uniformly high in the mud bank area averaging 35 mgC/m³/hour with the maximum potential productivity during the February-May period. This high rate is maintained by a constant replenishment of nutrients from the nutrient-rich bottom. The potential productivity is translated into real productivity when conditions for light penetration are favourable. At other times the area

forms a rich forage ground for the pelagic fishes and prawns which accounts for the abundant catch at a season when rough conditions prevail outside the area of the formation of mud bank.

Table 15. Productivity parameters of the Alleppey mud bank, Averages for the mud bank season(June-September) and those preceding and succeeding seasons (pooled for the four stations)

| Period | sample | Chlorophyll a mg/m ³ | Phytoplankton cells/l | Potential assimila- tion mgC/m ³ / hour | Assi- mila- tion ratios |
|------------|--------|------------------------------------|--------------------------|--|----------------------------------|
| June-Sept. | S | 21.80 | 272,700 | 26.06 | 1.2 |
| " | B | 22.16 | 139,300 | 58.43 | 2.8 |
| Oct.-Jan. | S | 5.51 | 161,000 | 19.13 | 3.5 |
| " | B | 8.08 | 129,000 | 11.55 | 1.4 |
| Feb.-May | S | 3.11 | 171,000 | 72.06 | 23.2 |
| " | B | 3.19 | 136,700 | 34.51 | 10.8 |
| June-Sept. | S | 10.81 | 387,000 | 29.00 | 2.7 |
| " | B | 13.77 | 269,500 | 26.34 | 1.9 |

S- Surface

B- Bottom

Indian Ocean

Apart from the data so far collected from the seas around India (Table 16) the results of measurements by GALATHEA (Stemann Nielsen and Aabye Jensen, 1957), VITIAZ (Kabanova, 1961), AFRICANA II (Mitchell-Innes, 1967) and data sheets of ENTOM BRUUN and DINANTINA have been taken for computing the productivity of the Indian Ocean in general. For the oceanic regions the available data have been pooled and the average was taken for every 10° square. Isolines were constructed using these values.

The measurements of primary production in the Indian Ocean by GALATHEA were the first ones made with ^{14}C . All stations at middle latitudes in the western part outside the continental shelf were characterized by a production rate between 0.1 and 0.2 $\text{gC/m}^2/\text{day}$, the value normally found in tropical and subtropical oceanic regions in the absence of any pronounced admixture of nutrient-rich water from below. Over the shelf off Beira the average was 0.51 $\text{gC/m}^2/\text{day}$. On the Agulhas Bank, water from the lower boundary of the photosynthetic zone showed three and half times the rate of production from that of the surface under constant illumination, indicative of a distinct ascent of nutrient-rich water to the photosynthetic layer (Stemann Nielsen and Aabye Jensen, op.cit.) In the South Equatorial

Current a relatively high production rate, 0.22-0-23 $\text{gC/m}^2/\text{day}$, was found. The coast of Ceylon has a high production rate. Very high values were observed south-east of Java, where upwelling, fairly high concentration of inorganic phosphate at the bottom of the euphotic layer and a high plankton biomass have been demonstrated by Wyrki (1962). Summarizing all the measurements in the equatorial current systems of the Indian Ocean, Steemann Nielsen and Aabye Jensen (1957) concluded that the rate of production is moderately high in the whole region of the equatorial current systems and in restricted areas very high production is found. The absolute values, however, have to be enhanced by 1.47.

Kabanova (1961, 1968) reported that primary production in the open part of the ocean was low and did not exceed 0.01-0-03 $\text{gC/m}^2/\text{day}$. An increase in the value of primary production was observed in coastal waters and in the zones of ascent of deep water. In the Banda Sea the production reached 0.024 $\text{gC/m}^2/\text{day}$, while on the Australian shelf the value increased up to 0.45 $\text{gC/m}^2/\text{day}$. In the African Madagascar region it was 0.072 $\text{gC/m}^2/\text{day}$.

For the western Indian Ocean, Ryther et al. (1966) observed two large areas of low productivity, one to the north extending from 80° to nearly 60°E longitude and

from the Indian Continent to about 5°S latitude and another from 10° to about 40°S latitude and from 80° E nearly to the African coast south of Madagascar. ANTON BRUUN measurements do not include any from the coast. But measurements given earlier indicate that the level of production is high towards the coast and becomes less seaward. The annual rate of gross production is ca 400 gC/m² practically anywhere on the shelf within 50 metres depth, 150 - 200 gC/m² between 50 and 200 metres and 50 gC/m² outside the shelf.

North of the equator Ryther et al. (loc.cit.) observed values of primary production increasing to the north and west reaching exceptionally high values off the coasts of Saudi Arabia and Pakistan. The average for 23 measurements in that region was more than 1.0 gC/m²/day observed off the south-eastern tip of Arabia. Based on these measurements, Ryther et al. (1966) calculated that for the western Indian Ocean, where the ANTON BRUUN survey was carried out for an area of 23×10^6 sq.km (about half of the Indian Ocean region now being considered or one-third of the Indian Ocean as conventionally mentioned), the annual productivity is 3×10^9 tons of carbon which gives an average of 0.35 gC/m²/day. But because of the great contrast in the relative productivity in this region the average value has not much

significance. About half of the total production occurred in 20% of the area surveyed. The observations in the western half of the Arabian Sea are summarized by Wooster et al. (1967).

Mitchell-Innes (1967) found for the region off South Africa, between latitudes 26° and 47°S, values ranging from 0.3 to 1.08 gC/m²/day. High productivity was observed ($> 0.5 \text{ gC/m}^2/\text{day}$) in Delgoa Bay and off Port Elizabeth. Burchill (1968 a,b) observes values ranging from 0.02 to 0.94 gC/m²/day) in the Agulhas Current region off Natal. Areas of high primary production were located in the vicinity of the continental shelf and also at the eastern boundary of the Agulhas Current.

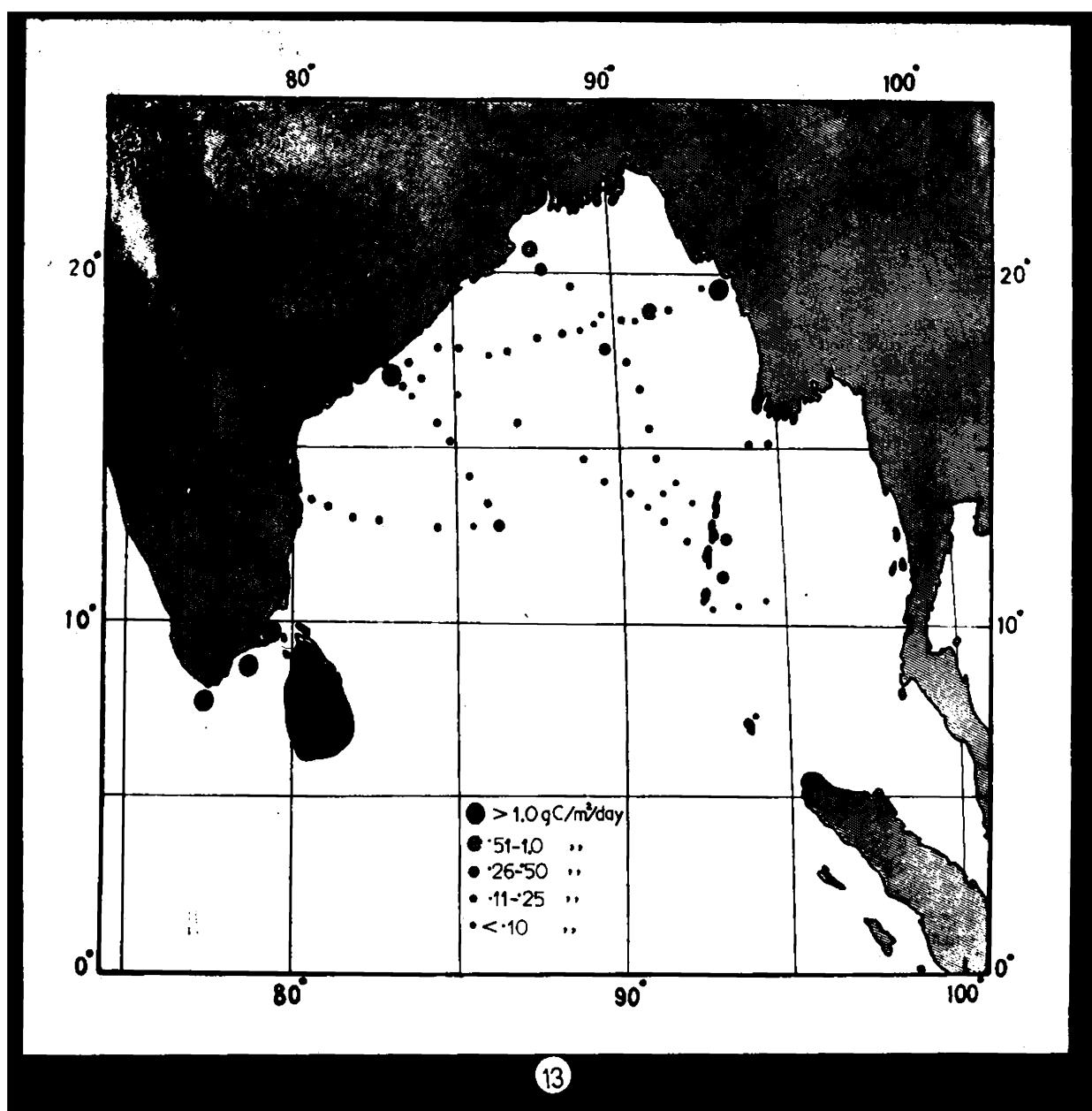
The average rate of production for the western half of the Indian Ocean is a little higher than the eastern half being 0.40 and 0.32 gC/m²/day respectively (80°E longitude is taken as boundary). Hence the annual gross production for the western half comprising 29×10^6 sq.km is 3.83×10^9 tonnes of carbon and for the eastern half comprising 22×10^6 sq.km is 2.67×10^9 tons.

For the Bay of Bengal area much data on the primary production are not available. Though it is a proper part of the Indian Ocean the salinity is relatively low through

the supply of fresh water. According to Steemann Nielsen and Aabye Jensen (1957) who provide the first data on productivity from this region, extensive investigations during different seasons are necessary in order to get a true picture of the productivity of the Bay of Bengal, as the monsoon shift has considerable influence on the hydrography and productivity of this area.

Lafond and Lafond (1968) have investigated the water motion during the cruise of R.V. ANTON BRUUN. They report that the duration and intensity of upwelling on both sides of the Bay of Bengal is not as great as in the western Arabian Sea. The areas of highest phytoplankton concentration were near shore on the northern and eastern sides of the Bay where there was replenishment of nutrients due to upwelling. The subsurface water rich in nutrients was found in the northern regions by the GALATHEA Expedition. The depth of euphotic zone was 45-66 metres at the western region and 84-99 metres in the eastern region indicating low productivity (Steemann Nielsen and Aabye Jensen, 1957). The lower transparency in the western part is presumably due to the organic and inorganic material conveyed by the rivers which decrease the rate of photosynthesis per surface area. Fig.13 shows the daily rates of production as reported by GALATHEA and ANTON BRUUN

Fig.13. The rates of primary production in the Bay of Bengal. The values from the Gulf of Mannar and Palk Bay on the south-east coast of India and the Andaman Sea are based on the candidate's observation. Rest of the values in the Bay of Bengal proper are based on GALATHEA and ANTON BRUUN reports.



(Stemann Nielsen and Aabye Jensen, (loc.cit.) and Woods Hole Oceanographic Institution Data Sheet, 1964).

Distribution map of primary production given by Kabanova (1968) for the Bay of Bengal during winter indicate values between $0.75-1.45 \text{ gC/m}^2/\text{day}$ for the south-east coast of India and between $0.33-0.75 \text{ gC/m}^2/\text{day}$ for the Andaman Sea. Localised high values are found towards the northern end of the Bay of Bengal and in the Gulf of Martaban.

The average value obtained for the shelf is $0.63 \text{ gC/m}^2/\text{day}$ which is about the value obtained by Steemann Nielsen and Aabye Jensen (1957) at station 503 ($20^{\circ}37'N$, $84^{\circ}30'E$) where the depth is 62 m and the euphotic zone 51 m. The observation was in April, which is not the period of high production on the east coast. The results of studies in Palk Bay show that the latter half of the year is characterised by a high rate of production. Kabanova (1968) also reported high production during the north-east monsoon period (October-December) on the Orissa coast, off Sanger Island and between Burma and the Andaman Islands. Outside the shelf the average production is about $0.19 \text{ gC/m}^2/\text{day}$.

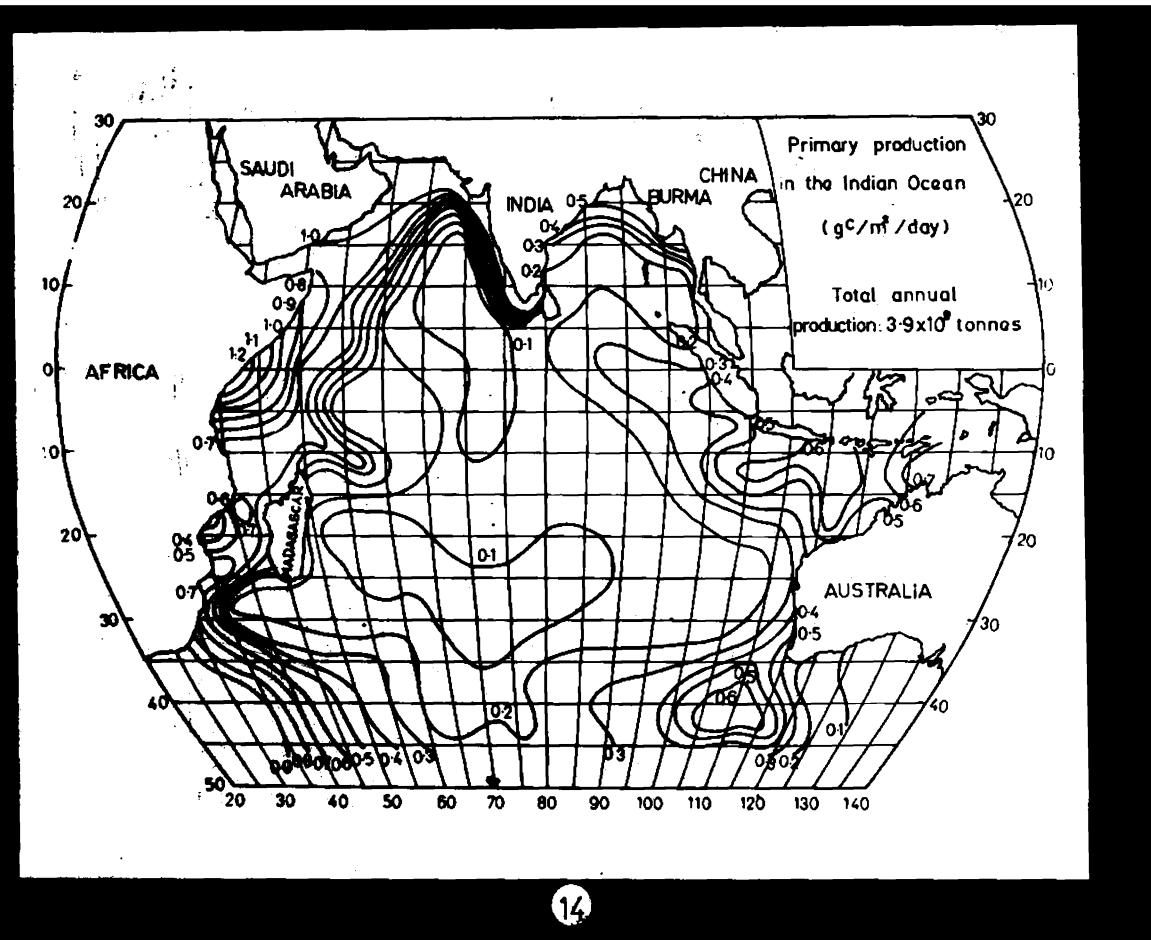
The annual gross production for the east coast of India on the shelf would amount to 25×10^5 tons of carbon or about one-third that on the west coast, which has a

broad shelf and more pronounced upwelling.

Allowing 40% of the primary production for respiratory requirement the annual net production for 5.1×10^6 sq.km of the Indian Ocean is 3.9×10^9 tonnes or about one-fifth of the estimated world oceanic production (Fig. 14).

As indicated before the continental shelf has a mean gross production of $0.85 \text{ gC/m}^2/\text{day}$. In view of an annual gross production of ca. 400 gC/m^2 observed in the coastal regions of the Indian seas the above value is only minimal. Accordingly the annual gross production for 5.1×10^6 sq.km of the shelf areas in the Indian Ocean would amount to 0.93×10^9 tons of carbon, and the net production 0.56×10^9 tons. Approximately 6% of the total area accounts for about 14% of the entire production. These estimates form the general basis for the computation of the potential yield of fish which is given in the last chapter.

Fig.14. Rates of primary production in different regions of the Indian Ocean. Isolines are based on averages from pooled data for every 5° square. Apart from the candidate's, data collected during the IIGE have also been used to derive the average value for each square.



**Table 16. Values for primary production expressed as
μC/m²/day with station positions, depths
and dates.**

| Date | Position | | Depth in metres | Production μC/m ² /day |
|------------|---------------|----------------|--------------------|--------------------------------------|
| | Latitude N | Longitude E | | |
| 4--6-1965 | 7°30' | 76°00' | 1,500 | 0.33 |
| 5--6-1965 | 8°00' | 77°20' | 38 | 2.09 |
| 6--6-1965 | 8°50' | 75°20' | 1,200 | 0.03 |
| 7--6-1965 | 9°30' | 75°10' | 2,000 | 0.13 |
| 12-10-1965 | 9°50' | 75°26' | 2,000 | 0.11 |
| 13-10-1965 | 9°20' | 75°39' | 400 | 0.16 |
| 14-10-1965 | 8°44' | 75°38' | 350 | 0.05 |
| 15-10-1965 | 7°53' | 77°04' | 550 | 0.53 |
| 16-10-1965 | 8°15' | 75°47' | 1,200 | 0.06 |
| 11-11-1965 | 7°56' | 76°55' | 70 | 0.07 |
| 11-11-1965 | 7°52' | 76°38' | 900 | 0.22 |
| 12-11-1965 | 8°32' | 76°00' | 200 | 0.13 |
| 12-11-1965 | 8°32' | 76°21' | 300 | 0.01 |
| 13-11-1965 | 8°43' | 75°26' | 800 | 0.13 |
| 15-11-1965 | -- | -- | 200 | 0.50 |
| 24-11-1965 | 11°26' | 74°51' | 82 | 0.11 |
| 25-11-1965 | 12°20' | 74°40' | 58 | 0.05 |
| 25-11-1965 | 12°40' | 74°15' | 86 | 0.27 |
| 27-11-1965 | 13°30' | 73°00' | 1,600 | 0.21 |
| 27-11-1965 | 13°30' | 73°30' | 180 | 0.10 |
| 28-11-1965 | 12°20' | 74°21' | 180 | 0.14 |
| 29-11-1965 | 11°15' | 74°34' | 1,200 | 0.04 |
| 14-12-1965 | 11°10' | 75°10' | 60 | 0.57 |
| 15-12-1965 | 13°26' | 75°10' | 40 | 0.95 |
| 16-12-1965 | Karwar Bay | | 7 | 1.39 |
| 19-12-1965 | 12°30' | 74°16' | 180 | 0.04 |

(Contd. Table -16)

| 1 | 2 | 3 | 4 | 5 |
|------------|--------|--------|-------|------|
| 6--1-1966 | 14°09' | 73°20' | 160 | 0.25 |
| 7--1-1966 | 13°35' | 72°55' | 1,900 | 0.35 |
| 7--1-1966 | 13°06' | 73°33' | 1,800 | 0.28 |
| 8--1-1966 | 12°27' | 74°20' | 120 | 0.25 |
| 3--2-1966 | 9°40' | 76°00' | 40 | 0.18 |
| 21--4-1966 | 11°15' | 74°49' | 260 | 0.45 |
| 22--5-1966 | 11°40' | 76°08' | 1,400 | 0.05 |
| 5--2-1966 | 7°50' | 77°11' | 300 | 0.13 |
| 7--2-1966 | 9°30' | 75°35' | 1,000 | 0.07 |
| 8--2-1966 | 9°55' | 75°09' | 2,000 | 0.39 |
| 26--5-1966 | 12°50' | 75°05' | 180 | 0.13 |
| 7--6-1966 | 8°12' | 76°44' | 80 | 0.57 |
| 8--6-1966 | 8°46' | 76°10' | 150 | 0.38 |
| 25--6-1966 | 13°30' | 73°34' | 120 | 0.29 |
| 26--6-1966 | 11°56' | 74°11' | 1,700 | 0.22 |
| 7--8-1966 | 8°00' | 77°11' | 60 | 4.55 |
| 6--9--1966 | 9°00' | 76°28' | 25 | 1.24 |
| 7--9-1966 | 8°00' | 76°58' | 90 | 4.55 |
| 8-11-1966 | 16°30' | 73°40' | 110 | 0.11 |
| 8-11-1966 | 16°29' | 74°42' | 300 | 0.12 |
| 6-12-1966 | 11°15' | 74°55' | 120 | 0.09 |
| 9--3-1967 | 9°21' | 75°52' | 188 | 0.05 |
| 18--4-1967 | 10°27' | 72°41' | 1,600 | 0.12 |
| 29--4-1967 | 10°43' | 74°26' | 2,160 | 0.21 |
| 8--6-1967 | 10°28' | 72°42' | 1,900 | 0.06 |
| 9--6-1967 | 10°23' | 72°46' | 1,900 | 0.04 |
| 6--8-1967 | 12°44' | 74°28' | 56 | 0.18 |
| 7--8-1967 | 14°08' | 73°18' | 30 | 0.61 |

(Contd. Table -16)

| 1 | 2 | 3 | 4 | 5 |
|------------|--------|--------|-------|------|
| 31--8-1967 | 11°16' | 73°50' | 2,100 | 0.05 |
| 6--9-1967 | 9°52' | 76°10' | 18 | 2.37 |
| 7--9-1967 | 9°20' | 76°31' | 50 | 1.18 |
| 7--9-1967 | 8°42' | 76°35' | 35 | 1.26 |
| 8--9-1967 | 8°17' | 75°44' | 1,400 | 0.40 |
| 9--9-1967 | 7°45' | 77°19' | 50 | 0.48 |
| 9--9-1967 | 7°45' | 78°00' | 47 | 1.43 |
| 9--9-1967 | 7°45' | 76°43' | 183 | 0.42 |
| 10--9-1967 | 7°27' | 77°40' | 117 | 0.95 |
| 10--9-1967 | 7°32' | 76°41' | 850 | 0.95 |
| 20--7-1968 | 8°53' | 76°21' | 50 | 1.12 |
| 21--7-1968 | 10°29' | 75°51' | 57 | 0.89 |
| 22--7-1968 | 11°19' | 75°36' | 28 | 1.34 |
| 24--7-1968 | 12°08' | 74°58' | 57 | 2.45 |
| 10--3-1969 | 9°12' | 78°33' | 1,300 | 0.16 |
| 11--3-1969 | 7°39' | 78°15' | 630 | 0.20 |
| 13--3-1969 | 7°25' | 77°31' | 130 | 0.36 |
| 14--3-1969 | 7°15' | 76°27' | 1,550 | 0.30 |
| 8--4-1969 | 9°28' | 75°04' | 1,550 | 0.07 |
| 10--4-1969 | 9°52' | 74°08' | 1,550 | 0.27 |
| 10--4-1969 | 10°11' | 74°32' | 1,550 | 0.13 |
| 11--4-1969 | 10°17' | 73°16' | 1,550 | 0.22 |
| 12--4-1969 | 8°48' | 72°24' | 1,550 | 0.10 |
| 12--4-1969 | 8°58' | 72°57' | 1,550 | 0.14 |



(Contd. Table -16)

| 1 | 2 | 3 | 4 | 5 |
|-----------|--------|--------|-----|------|
| 13-1-1970 | 10°00' | 76°08' | 22 | 0.29 |
| 15-1-1970 | 9°45' | 75°41' | 130 | 0.90 |
| 28-1-1970 | 8°50' | 76°20' | 58 | 0.07 |
| 29-1-1970 | ,9°15' | 75°50' | 275 | 0.09 |
| 30-1-1970 | 9°48' | 75°37' | 250 | 0.31 |
| 18-3-1970 | 10°47' | 75°13' | 200 | 0.17 |

FACTORS INFLUENCING PRIMARY PRODUCTION

Light penetration and depth of the euphotic zone

One of the most obvious variable factors influencing primary production is the amount of solar radiation reaching the surface of the sea. The amount of radiation entering the sea surface depends upon the altitude of the sun and changing weather patterns. The intensity of the solar radiation and transparency of the water together determine the depth of the euphotic zone.

Based on lux meter measurements Qasim, Bhattathiri and Abidi (1968) have calculated the average radiation falling at Cochin as $250-550 \text{ g cal/cm}^2/\text{day}$, the maximum radiation being in January-February and the minimum in July. Unlike in temperate regions the variation between the maximum and minimum amount of radiation is very little here. This has a significant bearing on the seasonal variability of primary production.

It has been pointed out by Steemann Nielsen and Aabye Jensen (1957) that even if the incoming radiation is reduced by 50% the production per unit area would be about 80% of that on a clear day. With a decrease in light

intensity of one-third the photosynthetic rate per unit area is about two-third of that measured on a bright day. Only on extremely dark days when there is incessant rain the rate per unit area would be reduced ^{to} 18% when the light intensity at the surface would be only one-seventh of that on a bright day. Such days are few and far between and as such have no real effect on the overall seasonal production, since the maximum rate is observed in the June-September period, which includes the most cloudy days.

Of more significance than radiation is the transparency of the water, that determines the depth of the euphotic zone which in turn is influenced by the concentration of plankton and the presence of other particulate or dissolved substances which absorb light.

The light penetration and depth of the euphotic zone was studied on the west coast of India and the Laccadive Sea using a Tinsley irradiance meter. It consists of a dark cell mounted on gimbals and a sea cell mounted in a bridle, a galvanometer and milliammeter which measures directly the ratio of the light intensities falling on the sea cell and deck cell that is expressed in percentage. Both the deck cell and sea cell are fitted with Megatron photocell and Chance filters OB2 blue/green which are red-free.

Opal flashed glass placed over the filters diffuse the light falling on the cells and as these are flush with the rim of the deck cell it can receive full 180° of solid angle light.

The sea cell is lowered from the side of the ship and the readings are taken at depths of every two metres marked on the cable. The depth is thus determined by the amount of sea cell cable paid out. Both 'down readings' and 'up readings' are taken. Extinction coefficients are determined by plotting the logarithms of percentage transmission against the depth and also by using the formula:

$$P_5 = \frac{2.3 (\log r_0 - \log r_{10})}{10}$$

where P_5 is the extinction coefficient at 5 m depth, r_0 is the transmission ratio at the surface i.e. the ratio-meter readings, r_{10} transmission ratio at 10 m and so on (Gall, 1949). Table 17 A,B,C,D give the light penetration at some stations on the west coast and Table 18 gives the extinction coefficients for different depths at two stations.

Table 17. Light penetration measurements on the west coast using Tinsley irradiance meter.

A. $07^{\circ}30'N$ $76^{\circ}00'E$. Depth - 1415 m (June - bright day)

| <u>Depth (m)</u> | <u>Down readings</u> | <u>Upreadings</u> | <u>% of incident light</u> |
|----------------------|----------------------------|-------------------|----------------------------|
| | <u>% of incident light</u> | | |
| 0 | 75 | 40 | 3 |
| 5 | 45 | 30 | 5 |
| 10 | 25 | 20 | 12 |
| 20 | 18 | 10 | 28 |
| 30 | 10 | 5 | 45 |
| 40 | 3 | 0 | 75 |
| 50 | 1 | | |

B. $13^{\circ}35'N$ $73^{\circ}34'E$. Depth-120 (January - clear day)

| | | | |
|-----|-----|----|-----|
| 0.5 | 50 | 50 | 3.5 |
| 1 | 45 | 40 | 4 |
| 2 | 40 | 30 | 9 |
| 5 | 30 | 20 | 17 |
| 10 | 20 | 15 | 24 |
| 15 | 17 | 10 | 28 |
| 20 | 13 | 5 | 31 |
| 25 | 12 | 0 | 95 |
| 30 | 10 | | |
| 40 | 6 | | |
| 50 | 3 | | |
| 55 | 2 | | |
| 60 | 1.5 | | |

C. 11°10'N 75°10'E, Depth - 60 m (December - bright day)

| <u>Depth (m)</u> | <u>Down readings</u> | <u>Upreadings</u> | <u>% incident light</u> |
|----------------------|----------------------|-------------------|-------------------------|
| 0 | 50 | 25 | 1.6 |
| 1 | 43 | 20 | 3 |
| 5 | 20 | 15 | 5.5 |
| 10 | 9 | 10 | 9.5 |
| 15 | 5 | 5 | 20 |
| 20 | 2 | 2.5 | 38 |
| 25 | 1.2 | 1 | 60 |
| 30 | 0.7 | 0 | 80 |

D. 08°50'N 76°05'E, Depth - 200 m (June, cloudy day)

| | | | |
|----|----|----|-----|
| 0 | 43 | 12 | 2 |
| 1 | 32 | 10 | 3 |
| 4 | 13 | 8 | 5 |
| 5 | 10 | 6 | 8.5 |
| 6 | 9 | 4 | 13 |
| 10 | 3 | 2 | 23 |
| 14 | 1 | 0 | 55 |

Table 18. Light penetration and extinction coefficients

| Date | Position | Seale Depth (m) | Depth of measure- ment | % of surface light | Extinction coefficient |
|----------|--------------------|-----------------------|------------------------------|--------------------------|---------------------------|
| 4-6-1965 | 7°30'N 76°00'E | 1415 | 5 | 40 | 0.138 |
| | | | 15 | 20 | 0.033 |
| | | | 25 | 10 | 0.026 |
| | | | 35 | 5 | 0.120 |
| | | | 45 | 1.8 | 0.110 |
| 6-1-1966 | 13°35'N 73°34'E | 120 | 5 | 30 | 0.161 |
| | | | 15 | 20 | 0.066 |
| | | | 25 | 12 | 0.026 |
| | | | 35 | 7 | 0.051 |
| | | | 45 | 4 | 0.069 |
| | | | 55 | 1.8 | 0.069 |

In coastal and inshore regions transparency is very variable. In the Gulf of Mannar and Palk Bay the compensation depth is at about 6 m indicating a high quantity of suspended matter. On the west coast the euphotic zone is about 50-60 metres in the offshore waters (Fig.15) and less towards the coast (Fig.16). On cloudy days the euphotic zone shrinks to 14 metres even at the edge of the continental shelf (Fig.17).

Sechi disc was also used for a rough measurement of the depth of the euphotic zone. The sechi disc visibility

Fig. 15. Light penetration and depth of the euphotic zone in June on a bright day outside the continental shelf area. Dots - down readings, dashed line - up readings and continuous line the mean of the two.

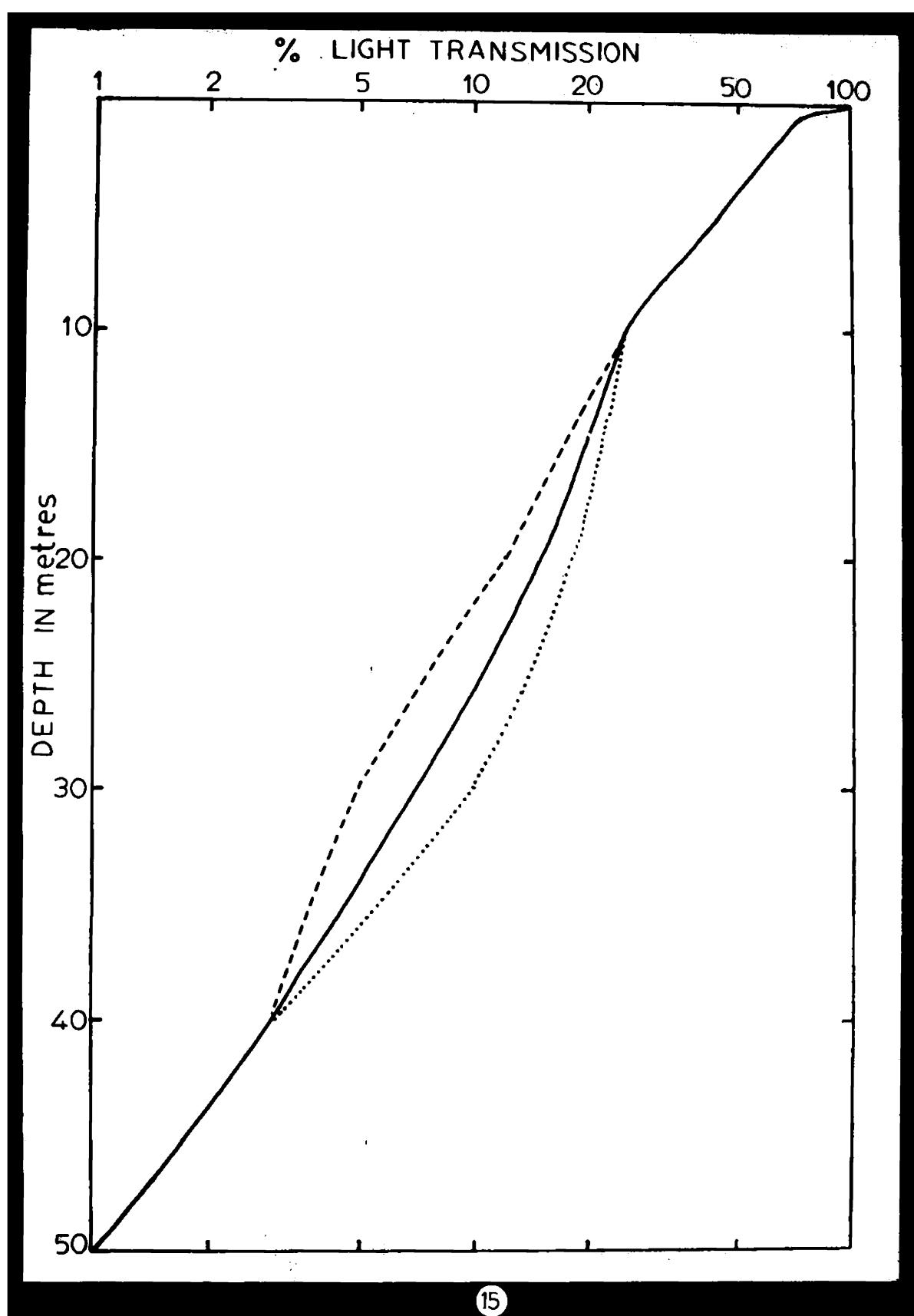


Fig.16. Light penetration and depth of the euphotic zone at a station inside the continental shelf (60 m depth) in December. Bright day but partly cloudy at the beginning of the measurement.

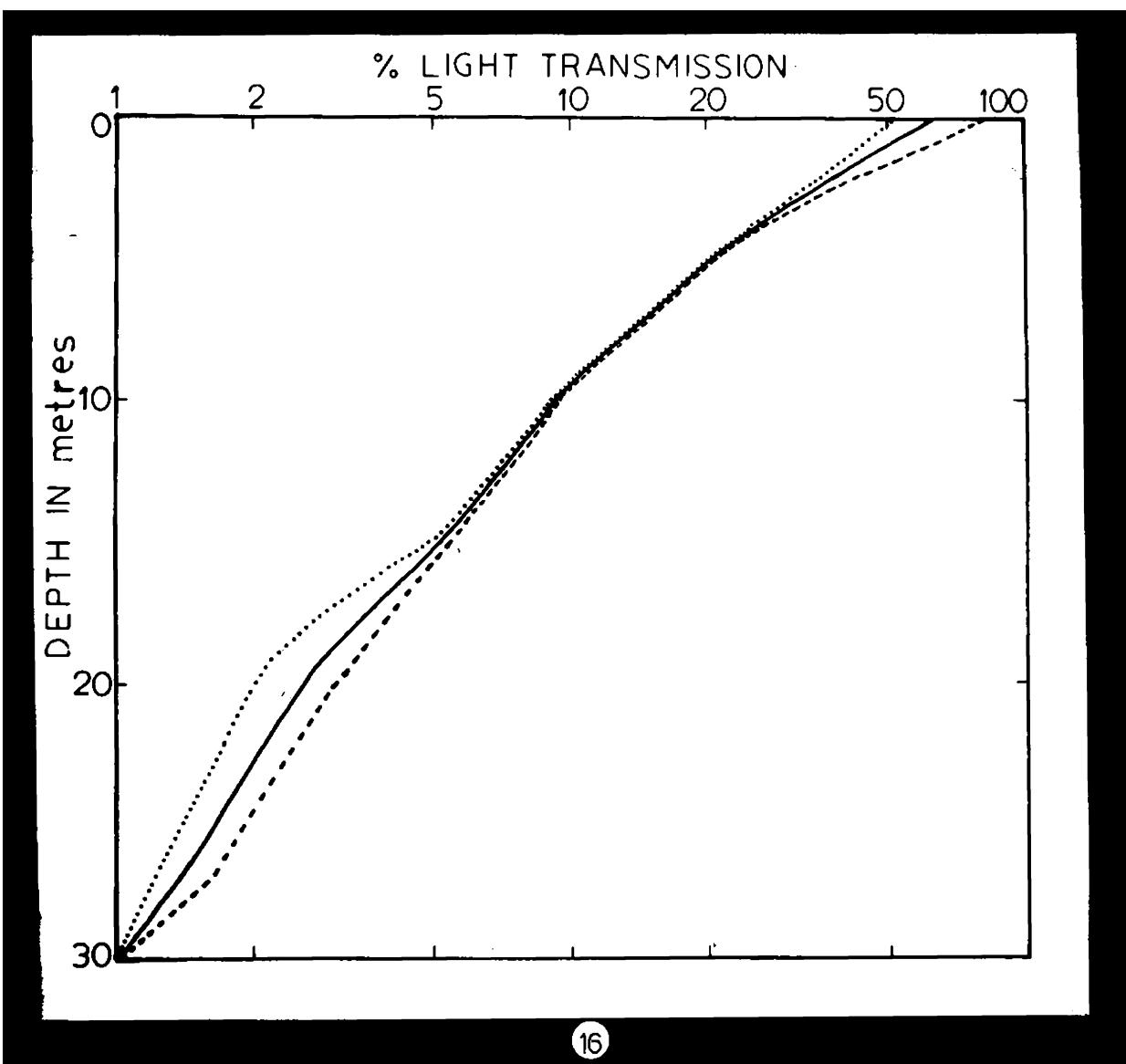


Fig.17. Light penetration and depth of the euphotic zone at a station on the shelf edge during June on a cloudy day.

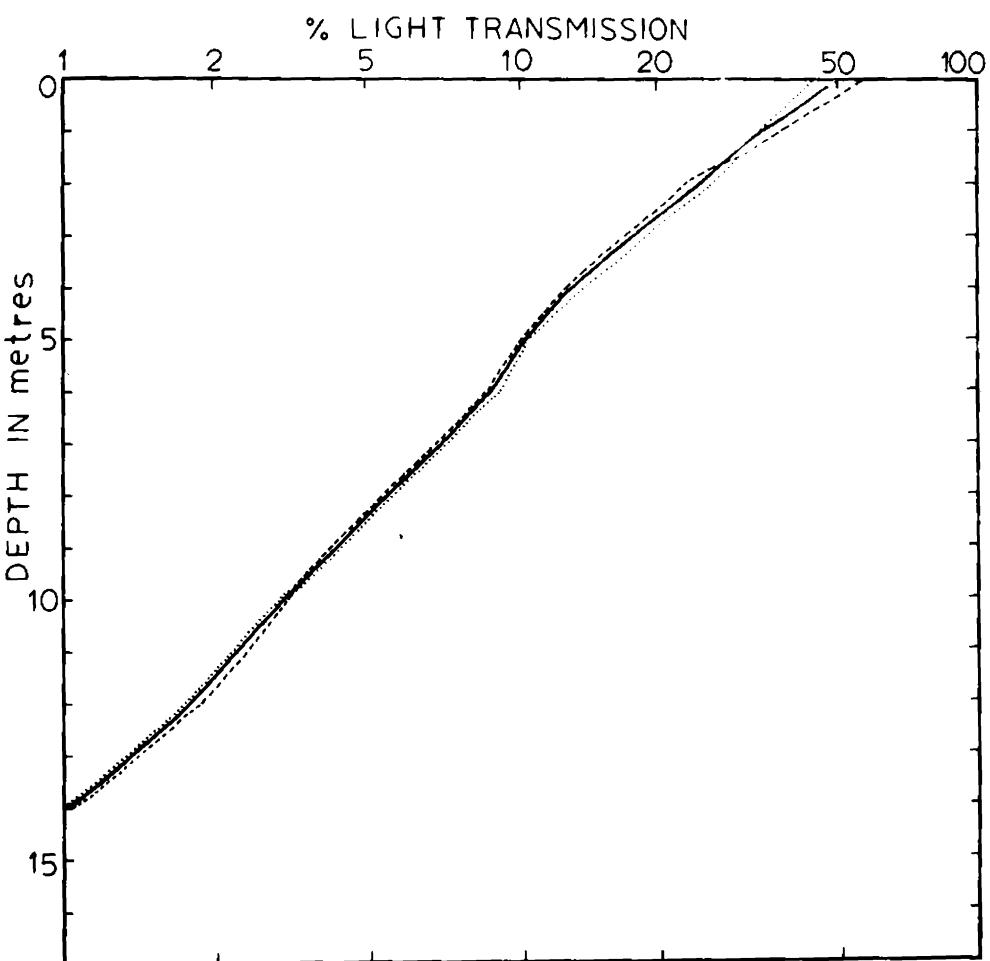
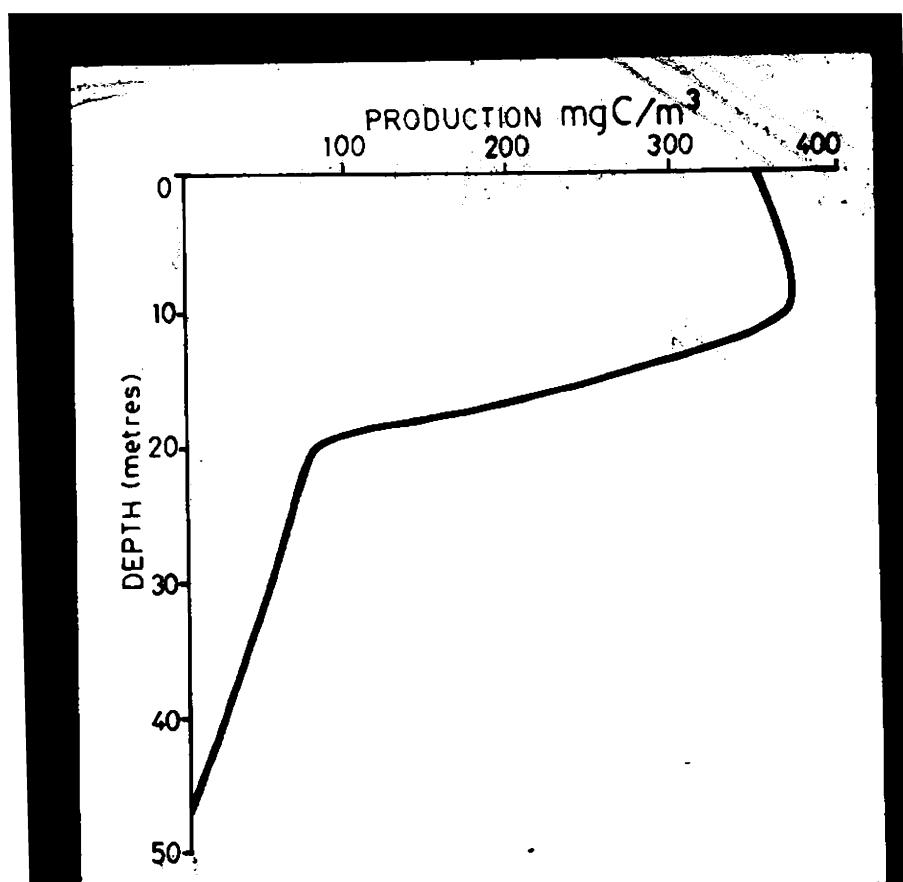
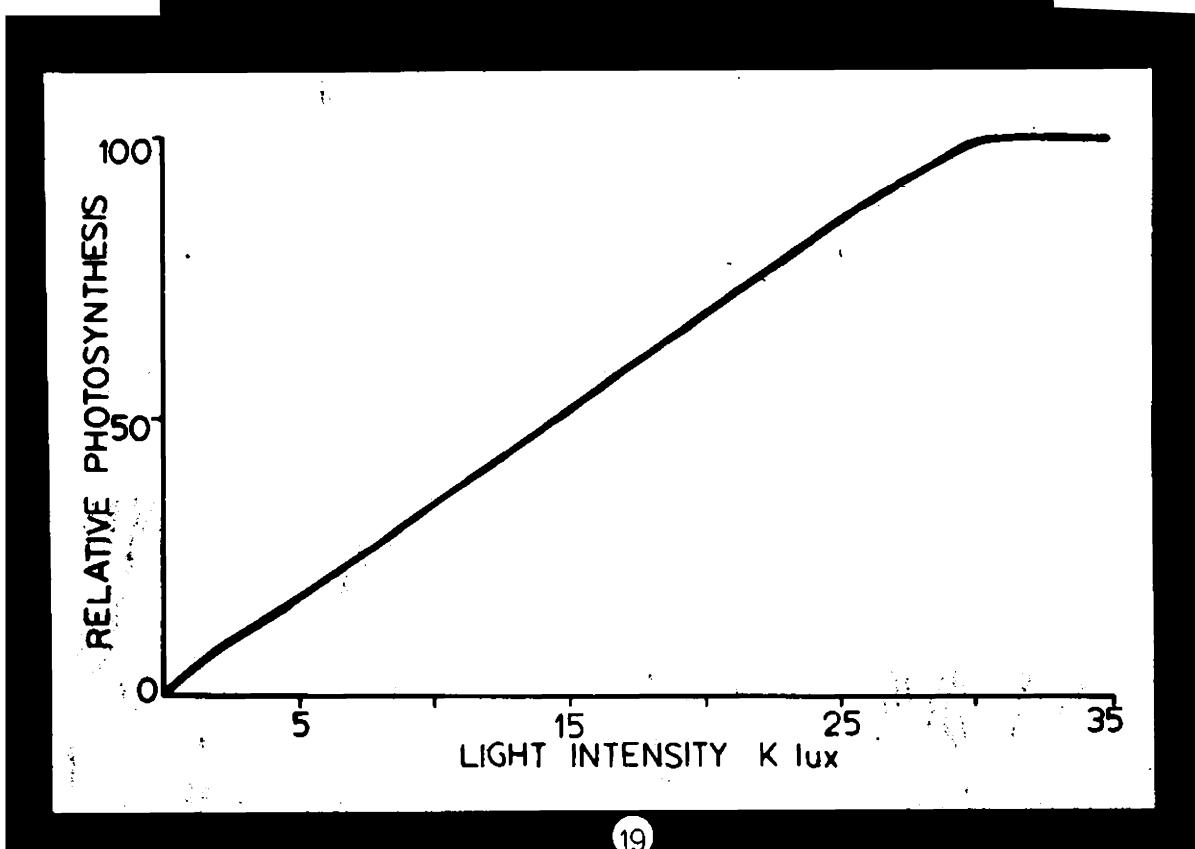


Fig.18. Rate of gross production as a function of depth
for a station in Gulf of Mannar off Tuticorin.
The measurements are from an in situ experiment.

Fig.19. Rate of photosynthesis as a function of light
intensity with surface plankton from $08^{\circ}17'N$
 $76^{\circ}45'E$.



18



19

of the maximum indicating only a slight inhibition. About 35% of the entire column production is within 20 metres. For the surface plankton of these waters the light saturation intensity continues until about 50,000 lux (Gundersen et al. 1969).

It may, however, be mentioned that recently Steemann Nielsen and Willmøes (1971) have pointed out that lux values, which several investigators have chosen to use in laboratory work with a definite light source, should now be abandoned. In field work it has no meaning with investigations on photosynthesis. In the absence of a quanta and energy meter the following conversion factors have been suggested:

$$\dagger \text{ lux daylight} = 0.41 - 0.50 \text{ mWatt} \times \text{cm}^{-2}$$

(Strickland 1958)

$$\dagger \text{ lux of fluorescent light} = 0.72 \text{ mWatt} \times \text{cm}^{-2}$$

$(1.7 \times 10^{15} \text{ quanta} \times \text{cm}^{-2} \times \text{sec}^{-1})$

(Steemann Nielsen and Willmøes, 1971)

Nutrients

The variations in the nutrient concentration along the west coast of India from Cape Comorin to Karwar and in the Laccadive Sea were studied during 1967-1968. The reactive phosphate was estimated by the revised method of

Strickland and Parsons (1965) using a composite reagent of ascorbic acid, molybdic acid and trivalent antimony. The nitrate was estimated using the copper-hydrazine method and silicate by the metol-exalic acid method of Strickland and Parsons (1960 and 1965).

The regional and seasonal variations in the nutrients in the upper layers show the same trend as in primary production. During the summer months preceding the monsoon, the nutrient concentrations near the coast as well as in the offshore areas are generally lower. The reactive phosphate varied from 0.20 to 0.38 μg at. P/l with very little gradient in the mixed layer. Near the bottom the values increased to 1.9 μg at. P/l. The nitrate values varied from 0.15 to 1 μg at. N/l and the silicate concentration ranged from 1.2 to 7.26 μg at. Si/l.

During the period of south-west monsoon (June to September) the nutrient concentration increases in the coastal regions. In the upper 20 metres between Gechin and Mangalore the level of phosphate concentration reaches 1.0 μg at. P/l. High values reaching 1.5 μg at. P/l are found off Mangalore where the maximum rate of primary production per unit volume has been recorded. The bottom values

in the waters over the shelf reach up to $2.0 \mu\text{g}$ at P/l. The whole continental shelf waters were rich in phosphate content during these months. A gradual increase from south to north was observed. As in the case of phosphate, nitrate and silicate values also were higher during this period. In the upper 50 metres near the coast, nitrate values ranged from 0.65 to $1.4 \mu\text{g}$ at. N/l, with the higher concentrations in the region north of Calicut. Silicate ranging from 2.5 to $7.5 \mu\text{g}$ at. Si/l were observed between Quilon and Mangalore.

During the post-monsoon period though there is a fall in the values of nutrients, the concentrations are high enough to maintain a moderately high rate of primary production. During the period of October to December the phosphate values ranged from 0.40 to $0.8 \mu\text{g}$ at. P/l in the southern regions between Cochin to Quilon. During the transition period of January-February the values were less.

In the mud bank area the nutrients were found to be in higher concentrations than in the other near-shore regions. 1.0 to $1.85 \mu\text{g}$ at. P/l observed during the summer months rises sharply to 2.5 to $3.75 \mu\text{g}$ at. P/l in a shallow area of 3.5 m depth. The nitrate values reach up to 2.50 to $3.45 \mu\text{g}$ at. N/l during the same period and so too the silicate

reaching 24.0 to 57.0 µg at. Si/l in the near bank area off Alleppey. During the post-monsoon and transition periods the silicate values fell to 4.6 - 11.7 µg at. Si/l when the values for the rest of the shelf were still less.

Thus the nutrient concentration in the waters over the shelf on the west coast of India follows a pronounced seasonal rhythm reaching the maximum during the south-west monsoon months. This has been observed by Reddy and Sankaranarayanan (1968) who inferred, from the vertical profiles of nutrients during the monsoon months, enrichment of coastal waters by the nutrients brought up from the subsurface levels.

A direct correlation between primary production and nutrient salts was observed by Kabaneva (1964) during the 33rd cruise of VITIAZ in the Indian Ocean - low values of primary production coincided with the deficiency of nutrient salts. In the central part of the Arabian Sea and in the open part of the ocean nitrate was absent and in the Bay of Bengal and in the Andaman Sea phosphates were almost exhausted by phytoplankton.

Hence it may be concluded that in the Indian seas the seasonal variation and magnitude of primary production are influenced primarily by the availability of nutrients since the other important factors are never limiting. However, in

very shallow regions where the bottom is always in contact with the overlying water, a low concentration of phosphate or other nutrients might lead to an erroneous inference as discussed in the next chapter. A low level of phosphate and the absence of a pronounced seasonal cycle is not symptomatic of a low rate of organic production as was observed in the Gulf of Mannar. As pointed out by Delsman (1939) a more rapid metabolism in the tropical seas would check an accumulation of nutrients.

Standing crop of phytoplankton

Monthly averages of phytoplankton cells, obtained by sedimenting and centrifuging surface samples from Station 61, varied from 360 cells/l in August to 583,000 cells /l in April. In the individual samples the variation was from 100 cells/l in the first week of August to 1,510,000 cells/l in the second week of April, the trend of variation being almost similar to that of primary production.

Koblenz-Mishke et al.(1970) remark that from the level of primary production in any particular region of the world ocean one can judge indirectly the relative variations in the number of phytoplankton cells. They found that despite the fact that the same production may correspond to the most varied counts of phytoplankton cells, there is a general correlation between the surface primary production

and standing stock of phytoplankton. On the average, a higher level of primary production corresponds to a greater concentration of phytoplankton. The relation between cell numbers and primary production is given in Fig. 20.

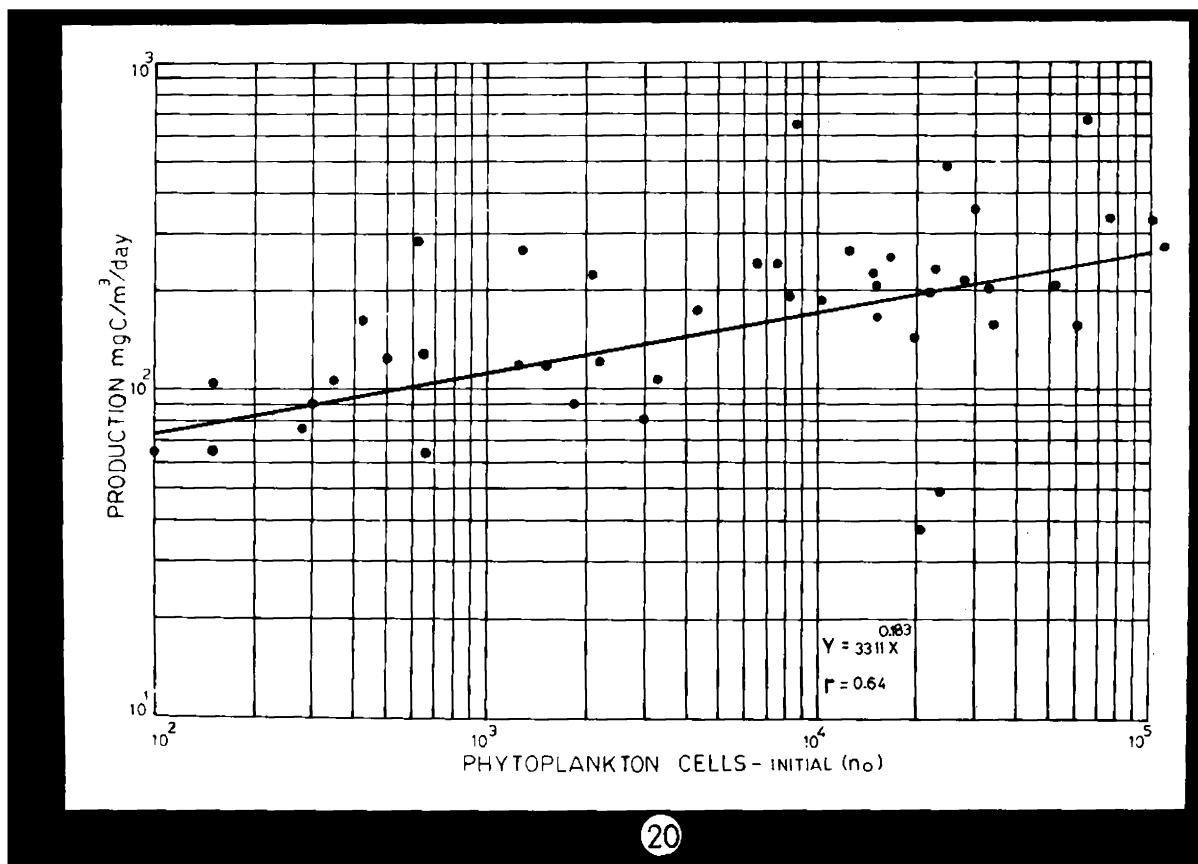
The measurements of chlorophyll concentration in the shallow regions do not seem to have much correlation with the standing crop. The earlier measurements in terms of Harvey Plant Pigment Units (HPPU) were converted to chlorophyll values by using the equivalent:

$$\text{mg chlorophyll} = (3 \pm 1 \times 10^{-4}) \times (\text{No. of HPPU's})$$

Accordingly the highest value of 23 mg/m^3 /chlorophyll was found in April followed by 15 mg/m^3 /in May and the lowest 2.7 mg/m^3 in October. The values obtained from calibration curves constructed out of chromatographically pure chlorophyll a were dissimilar to those obtained by the conversion method.

Recent measurements of chlorophyll a using a Unicam Spectrophotometer and by applying the revised equations of Parsons and Strickland (1963) showed chlorophyll a values ranging from 53 mg/m^3 to 69 mg/m^3 in April (Table 19). Higher values were generally recorded in the surface and near-surface samples excepting in one station where the maximum value was recorded at 10 m. The relationship between primary production and chlorophyll was not found to be significant. The correlation coefficient between log. primary

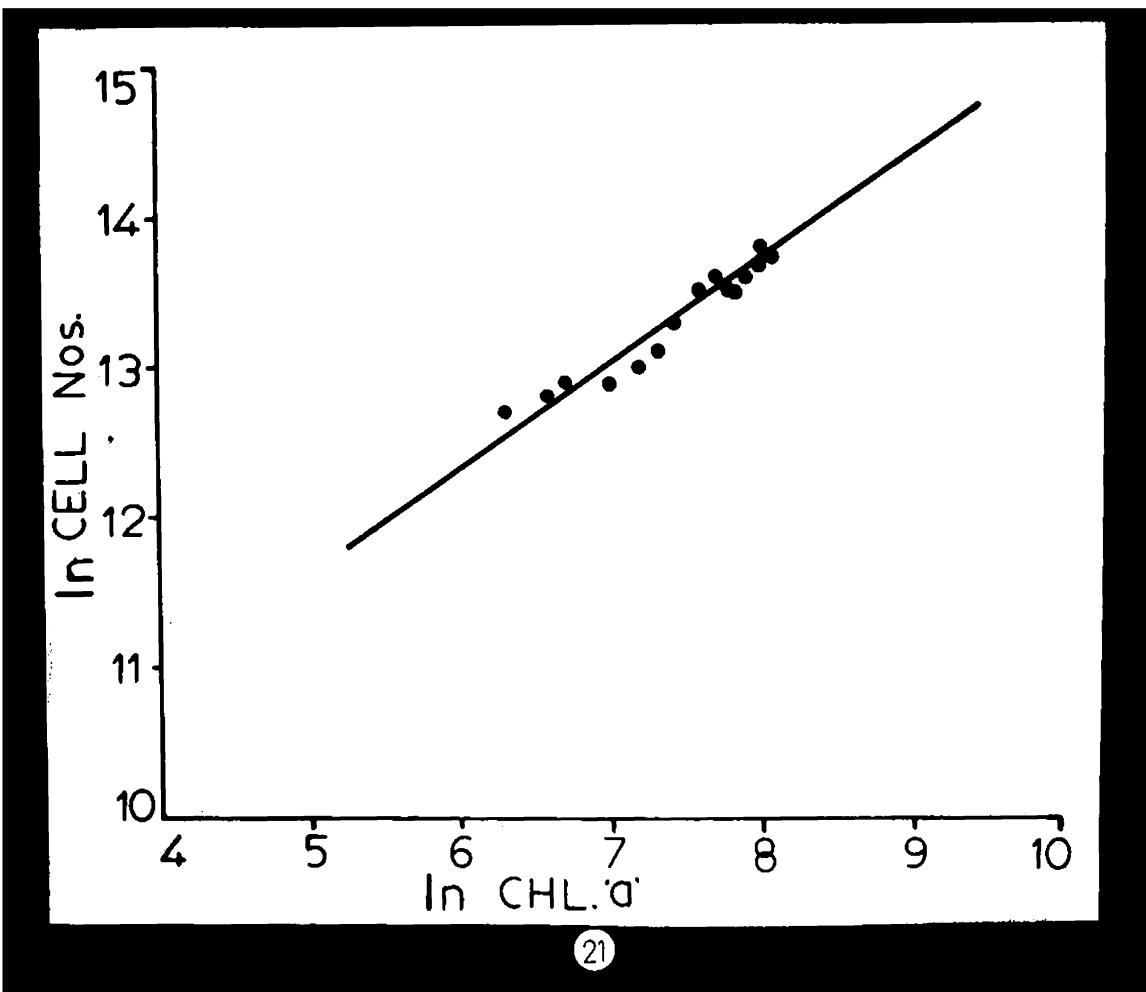
Fig. 20. The relation between surface primary production ($\text{mgC/m}^3/\text{day}$) and standing stock of phytoplankton (number of cells/l) at station 61.



production ($\text{mgC/m}^3/\text{day}$) and log.chlorophyll a was found to be +0.44, -0.32 and +0.61 at surface, 1 metre and 5 metre depths respectively. The 'r' value between log.chlorophyll a and log.phytoplankton cells was also not significant being 0.14.

In the earlier analysis, when 43 sets of values on pigments and number of cells spread throughout the year were taken into consideration the correlation coefficient was +0.542, which is highly significant. But for July to October it was -0.413. Hence it is felt that when the sea is cheppy with high winds the pigment/chlorophyll values and cell numbers do not give the expected positive correlation. But a plot of chlorophyll a against cell numbers in a growing culture of Tetraselmis (Fig.21) shows a strong relationship, as should be expected. The field measurements especially in the inshore regions are considerably influenced by many extraneous factors which make the values of pigments unreliable. As Krey (1973) observes, chlorophyll values would at most indicate only the degree or level of primary production in an area due to the amount of error introduced by the unknown quantity of inactive or dead chlorophyll a present in the standing stock.

Fig.21. The relation between cell numbers and chlorophyll
a in a growing culture of Tetraselmis gracilis.



(21)

Table 19. A few simultaneous measurements of primary production along with chlorophyll a and phytoplankton cell counts in the Gulf of Manar (April 73).

| Depth (m) | Chlorophyll a (mg/m ³) | Primary production (mg/m ³ /day) | Total No. of photo- cells/l |
|-----------|---------------------------------------|--|-----------------------------------|
|-----------|---------------------------------------|--|-----------------------------------|

1-4-1973: 08°55'N 78°25'E

Forenoon

| | | | |
|---|-------|-----|--------|
| 0 | 26.70 | 218 | 526600 |
| 1 | 21.36 | 406 | |
| 5 | -- | 226 | |
| 8 | 10.68 | 161 | |

Afternoon

| | | | |
|---|-------|------|--|
| 0 | 37.38 | 3912 | |
| 1 | 26.70 | 302 | |
| 5 | 32.04 | 232 | |
| 8 | 32.04 | 106 | |

2-4-1973: 08°54'N 78°22'E

Forenoon

| | | | |
|----|-------|------|--------|
| 0 | 42.72 | 148 | 124000 |
| 1 | 16.02 | 173 | 185600 |
| 5 | 37.38 | 302 | 113800 |
| 10 | 16.02 | 111 | 240000 |
| 15 | 10.68 | 3792 | 287000 |

(Contd. Table 19)

| 1 | 2 | 3 | 4 |
|----------------------------------|-------|------|--------|
| <u>Afternoon</u> | | | |
| 0 | 32.04 | 125 | 895200 |
| 1 | 16.02 | 187 | 361400 |
| 5 | 21.36 | 334 | 619900 |
| 10 | 32.04 | 285 | 861000 |
| 15 | 21.36 | 73 | 503100 |
| 20 | - | 4020 | |
| <u>3-4-1973: 09°50'N 76°13'E</u> | | | |
| 0 | 16.02 | 141 | 716900 |
| 1 | 26.70 | 231 | 163400 |
| 5 | 48.06 | 195 | 488100 |
| 10 | 69.42 | 123 | 133400 |
| 15 | 57.38 | 65 | 124200 |
| <u>4-4-1973: 00°20'N 76°30'E</u> | | | |
| 0 | 5.34 | 38 | 385200 |
| 1 | 26.70 | 29 | 126000 |
| 5 | 16.02 | 26 | 294000 |
| 10 | -- | 16 | 262000 |
| 30 | 10.68 | 31 | 264600 |

Standing crop of zooplankton

An analysis of the constituents of the zooplankters in the surface samples at station 61 reveal that broadly two groups could be recognised, one group of predominantly herbivores constituted by copepods, nematii, larval stages of decapods, lamellibranchs, polychaetes and other forms like eikepleura. Obligatory carnivores like chaetognaths and hydromedusae form the second group. The quantitative distribution of these groups varied seasonally (Table 20), and based on their occurrence in the samples the following generalisations are possible: Total number of zooplankters constituted mainly by the herbivores were generally high during most part of the year. A marked decline was noted during June. A numerical augmentation was recorded during November. Carnivores were numerically less throughout the period of observation. Prasad (1954) while studying the distribution and fluctuations of planktonic larvae of Mandapam remarked that there is possibly a relation between the phytoplankton production and the larval maxima, the latter coinciding somewhat with periods of abundant phytoplankton.

Table 20. Mean monthly figures of zooplankters in
2 litre samples.

| | JY. | A | S | O | N | D | J | F | M | A | M | J |
|-----------------------------|-----|----|-----|----|-----|-----|-----|-----|-----|----|-----|----|
| Predominantly herbivores | 73 | 95 | 108 | 46 | 567 | 147 | 128 | 101 | 120 | 79 | 124 | 34 |
| Carnivores | 4 | 3 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

Since phytoplankton is the food of the herbivorous zooplankton, in the long run, a large population can sustain only where the production of phytoplankton is high. An inverse relation between phytoplankton and zooplankton refers only to the momentary state of affairs, not the general relationship lasting over the whole year (Steemann Nielsen, 1958 e). The IOC data on the distribution of zooplankton biomass (Prasad, 1969) show that the average annual distribution agree well with the general distribution and regional variation in primary production. The highly productive areas are found around the Somali and Arabian coasts and to a certain extent on the south-western coast of India. The low productivity zones occupy the central part of the Arabian sea. The southern hemisphere, especially south of 10°S latitude, exhibits a very low zooplankton biomass, whereas the

regions south of the Indonesian Archipelago and the western coast of Australia show a higher density of zooplankton. The estimated biomass for the Indian Ocean comprising 51 million sq.km. of the Indian Ocean is 5.2×10^8 tonnes as against 3.9×10^9 tonnes of annual net production of carbon (Prasad, Banerji and Nair, 1970).

Discussion

To evaluate the primary production in natural habitat, the size of the gross production and the net production must be known. In the final reckoning with ^{14}C measurements some corrections and assumptions are inevitable to get either of the values. Thomas (1961) has summarised the four conditions which are to be met for the measurement of gross production by ^{14}C . Of these, the correction for the difference in the rate of assimilation of ^{14}C and ^{12}C has been ascertained at 6% (Steemann Nielsen, 1952 and 1955).

The correction for non-photosynthetic uptake of ^{14}C is made by incubating a dark sample. This has been normally found to be about 1% in the surface samples and increasing towards the bottom. In certain rare instances bacterial fixation in the dark was found to be higher than photosynthetic fixation of ^{14}C (Table 19). Radhakrishnan (1969)

observed an average 42% dark fixation, with a range of 24 to 115% at the bottom of the euphotic zone, in the shelf regions of the west coast. Steemann Nielsen (1960b) has also observed values upto 30% for bottom samples. In view of such variability dark bottle corrections have been preferred over standard corrections.

The loss of extracellular products can vary from 1 to 20% as observed by Samuel, Shah and Fogg (1971) in these waters. Similarly the retention capacity of the filters differs according to the nature of the population. Hence the right selection of the filters, depending on the nature of the population, is also necessary in order to obtain accurate results. Millipore HA filters, which have been used for routine measurements, were found to have the maximum retention in the more productive inshore environments though they lose some radioactivity (3-15%) compared to Gelman filters having a pore-size of 0.30μ , when the population is sparse. Göttingen membrane filters also were found to lose about 4 to 19% under the same conditions. But when the population is dense, the filters with smaller pore size ($< 0.45 \mu$) lose the activity probably due to rupture of the cells.

The magnitude of correction for respiration that accompanies photosynthesis is rather uncertain. This correction is dependent upon the rate of respiration relative to that of gross photosynthesis. The crucial aspect of the correction for respiration is the P/R ratio, and the amount of intermixing of the two processes is of less importance (Thomas, 1961).

Steemann Nielsen and Hansen (1959) have described a method for measuring respiratory rate of autotrophic phytoplankton by means of ^{14}C technique. A curve showing the rate of net photosynthesis as a function of light intensity is obtained and by extrapolation the rate of respiration is deduced. Figs. 22 and 23 give rates of respiration, obtained by extrapolation, of surface samples from the Gulf of Mannar and Laccadive Sea. In both half the optimal rate was achieved at 10,000-11,000 lux. The rate of respiration obtained is rather high but not unusual—25% in the Gulf of Mannar and 30% in the oceanic sample from the Laccadive Sea. Qasim *et al.* (1969) observed respiration (day) as a percentage of gross varying from 20.6 to 45.5% in the Cochin backwater.

According to Steemann Nielsen and Hansen (1959) the rate of respiration in percentage of light-saturated photosynthesis is mostly 15% or less and in tropical surface

Fig.22. Rate of photosynthesis as a function of light intensity Surface plankton from the Gulf of Namur. (Dashed line gives the corrected values)

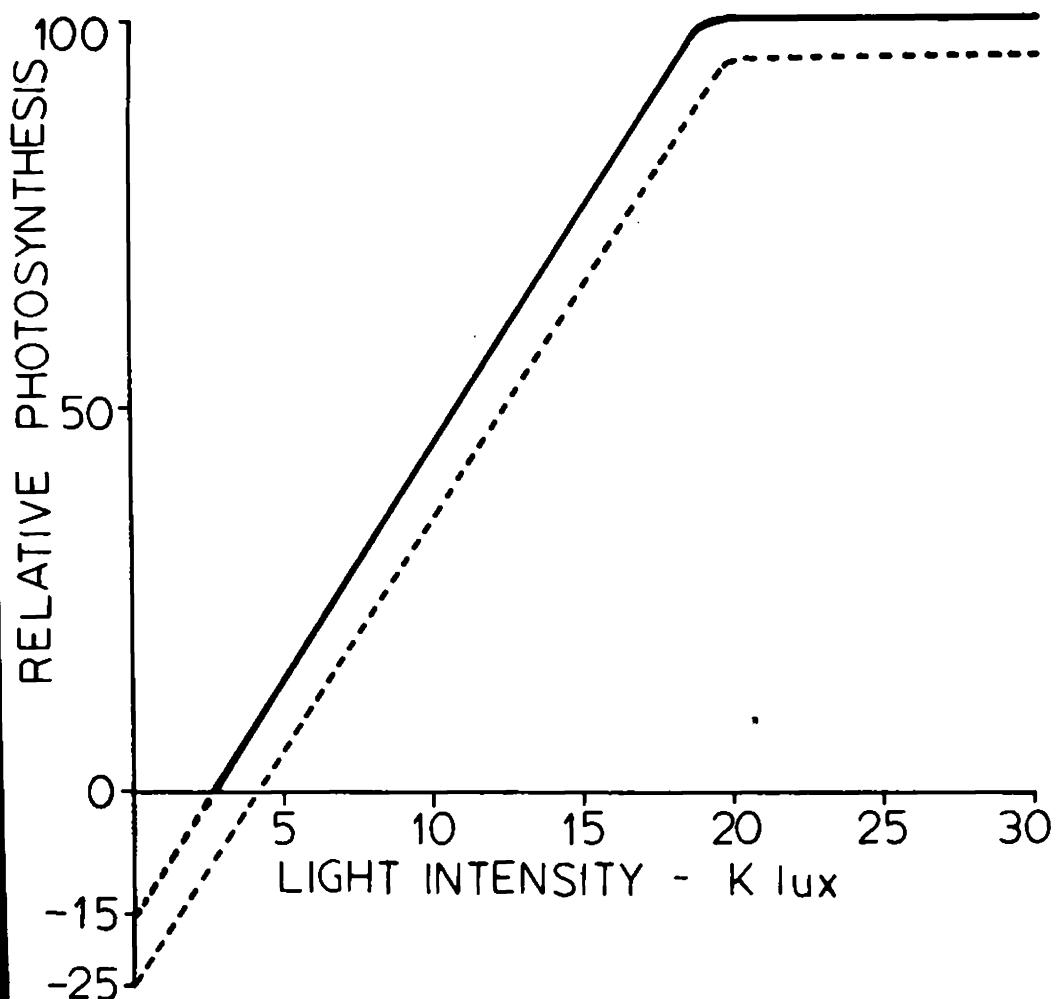
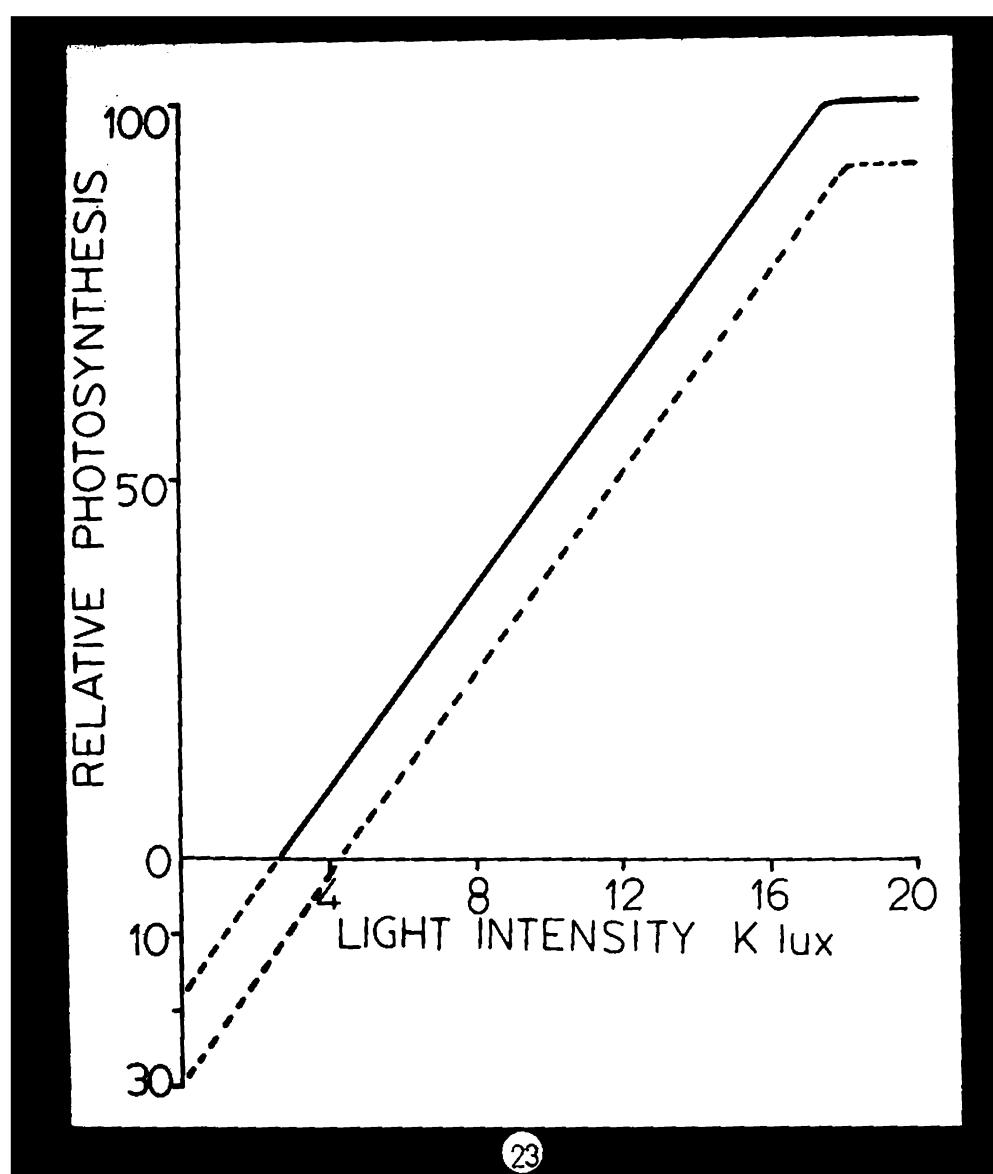


Fig. 23. Rate of photosynthesis as a function of light intensity with Surface plankton from 11°19'N,
74°53'E (July). Dashed line represents corrected values.



plankton generally below 10%. These authors also point out that the variation of the respiratory rate as a percentage of the maximum rate of photosynthesis is within a range of 5-25% and a rate of respiration higher than 30% of the optimum photosynthetic rate will, even in the upper half of the photic zone when integrated for all the algae found there, give rise to a decrease in the stock of algae. The higher rate observed by Qasim et al. (1969) is perhaps contributed by the zooplankters as the measurement is made from the oxygen decrease.

In the laboratory measurements with a culture of Tetraselmis a respiration rate of 37% was observed - Fig. 24. (Fig. 25 gives the respiration rate without the dark correction). Since the dark uptake was rather high it is presumed that the cells would have been N-deficient, as demonstrated by Steemann Nielsen and Al Kholy (1956). The influence of a respiratory rate differing from that arbitrarily chosen (10%) is insignificant if the rate of gross production only is wanted (Steemann Nielsen and Hansen, loc.cit.). Hence all the values are given as gross production. But for the calculation of the net production per surface area per 24 hours the variation in the respiratory rate is more important. For want of a more accurate estimation

Fig.24. Rate of photosynthesis as a function of light intensity with a culture of Tetraselmis gracilis.
The continuous line presents the values after making correction for dark uptake and the dashed line corrected values for respiration.

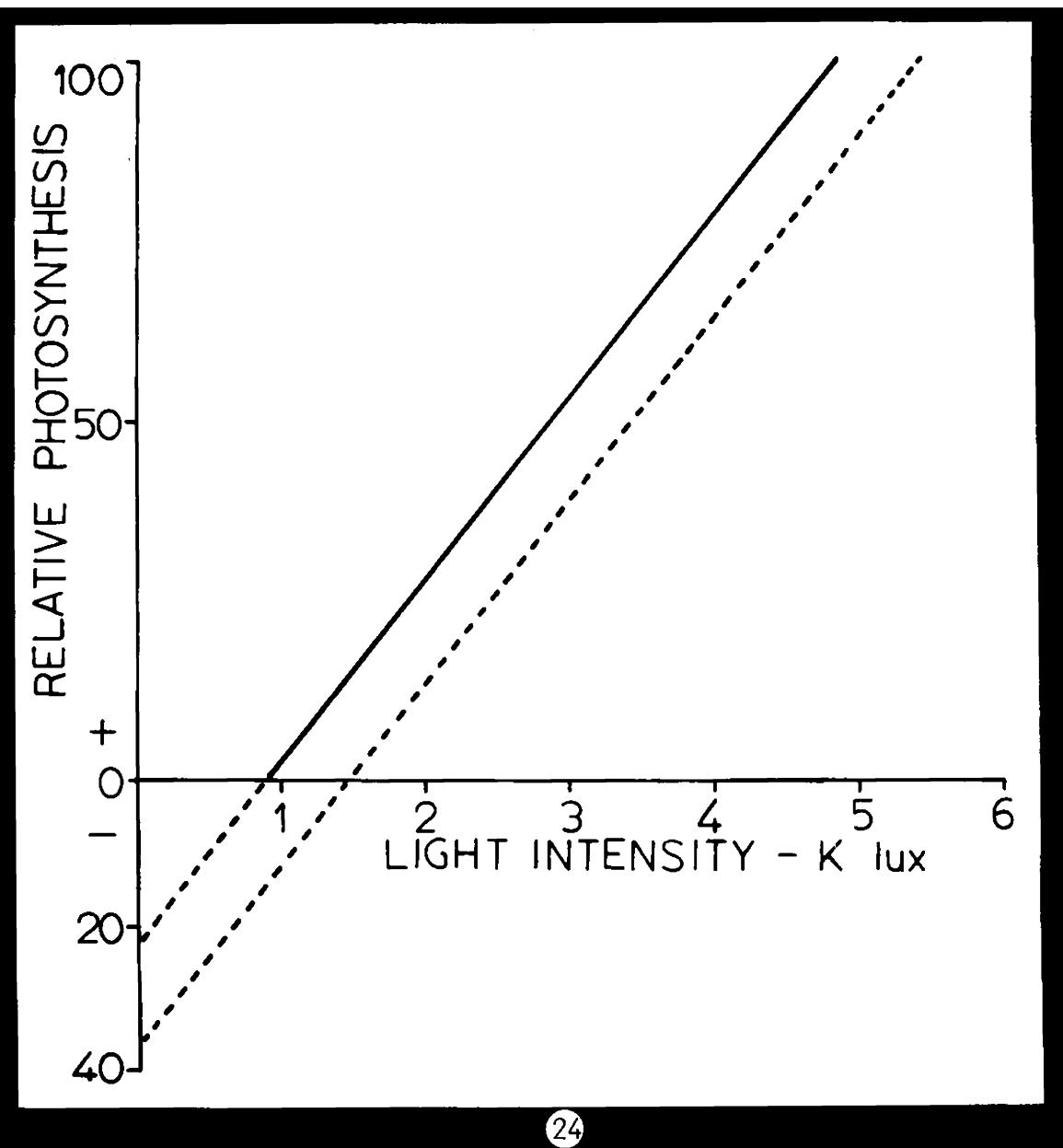
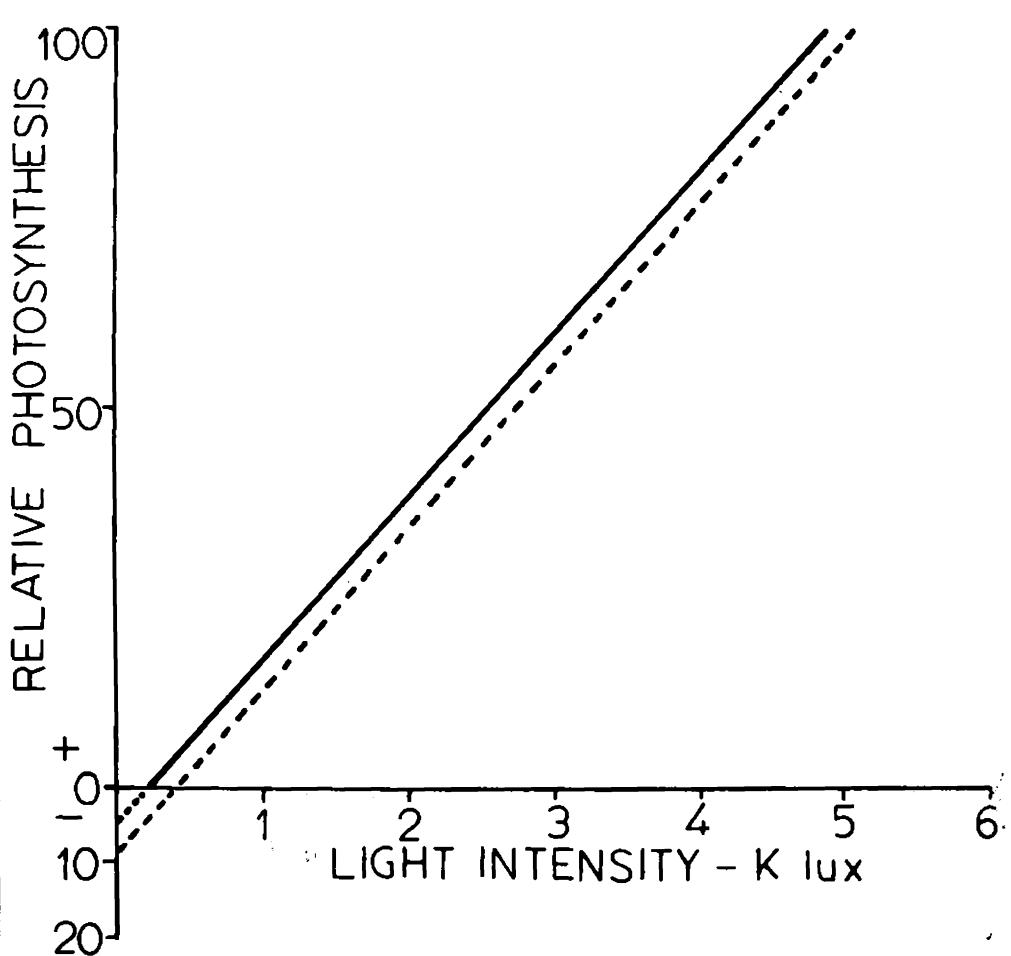


Fig.25. Same as in Fig.24 but without correction for dark uptake. The continuous line presents the observed values and the dashed line corrected values.



25

of respiration at different light depths during different light conditions, total net production for computation of potential yield has been taken as 60% of gross production.

The magnitude of primary production and its seasonal and regional variability in the Indian seas are influenced primarily by the availability of nutrients and the transparency of the water which affects depth of the euphotic zone since other parameters such as light or temperature are never limiting factors. It is also obvious that from the studies on the seasonal variation of the different phosphorus fractions. In the Gulf of Mannar it is not the instantaneous concentration of the essential elements that is important but the rate of replenishment (cf. Ketchum, 1947). In the Gulf of Mannar and Palk Bay if the replenishment is caused by wind and wave action, on the west coast it is by the processes associated with upwelling of deep waters and ocean currents.

The bottom mud especially on the west coast is a rich store house of nutrients which are released into the waters during the south-west monsoon generally and during periods of high winds when a mixing up of the layers occurs. Seshappa (1953) and Seshappa and Jayaraman (1956) investigated the bottom muds of an inshore area on the west coast.

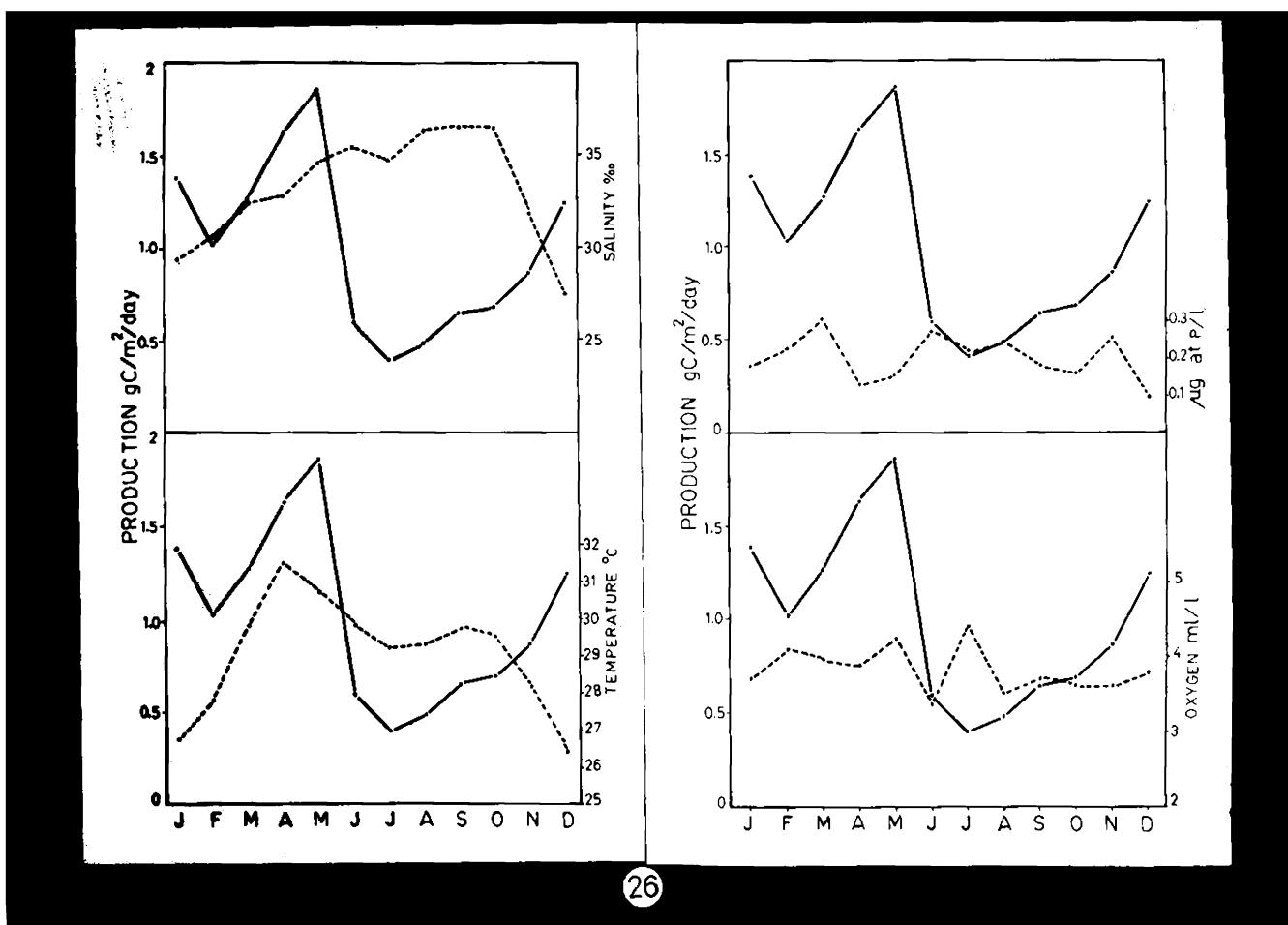
They found that the values for interstitial phosphate were higher than corresponding values for inorganic phosphate in the overlying water during the pre-monsoon months and that the mud retains relatively large quantities of phosphate and other nutrients. It was also observed that the mud is of laterite origin and an analysis of the sample of laterite by them revealed high adsorbed phosphate.

Another cause for the increase of phosphate during the south-west monsoon months is attributed to the death and decay of bottom fauna at the commencement of the season. It is therefore likely that during the south-west monsoon season the phosphate in the mud is also released by high winds apart from the supply generated by the process of upwelling. These may explain the high concentration of phosphate in the waters of the west coast during the bloom of phytoplankton unlike in the Gulf of Mannar. Obviously there is more phosphate in the inshore waters of the west coast than is required for the growth of phytoplankton (Subrahmanyam, 1959). Later with the onset of calmer conditions the death and decay of the plankton that sink to the bottom liberate phosphates in the bottom sediments which become available again during the next monsoon. This cyclical seasonal exchange of phosphorus between the sediment and water has been confirmed for the west coast by Seshappa (1953) and Seshappa and Jayaraman (1956).

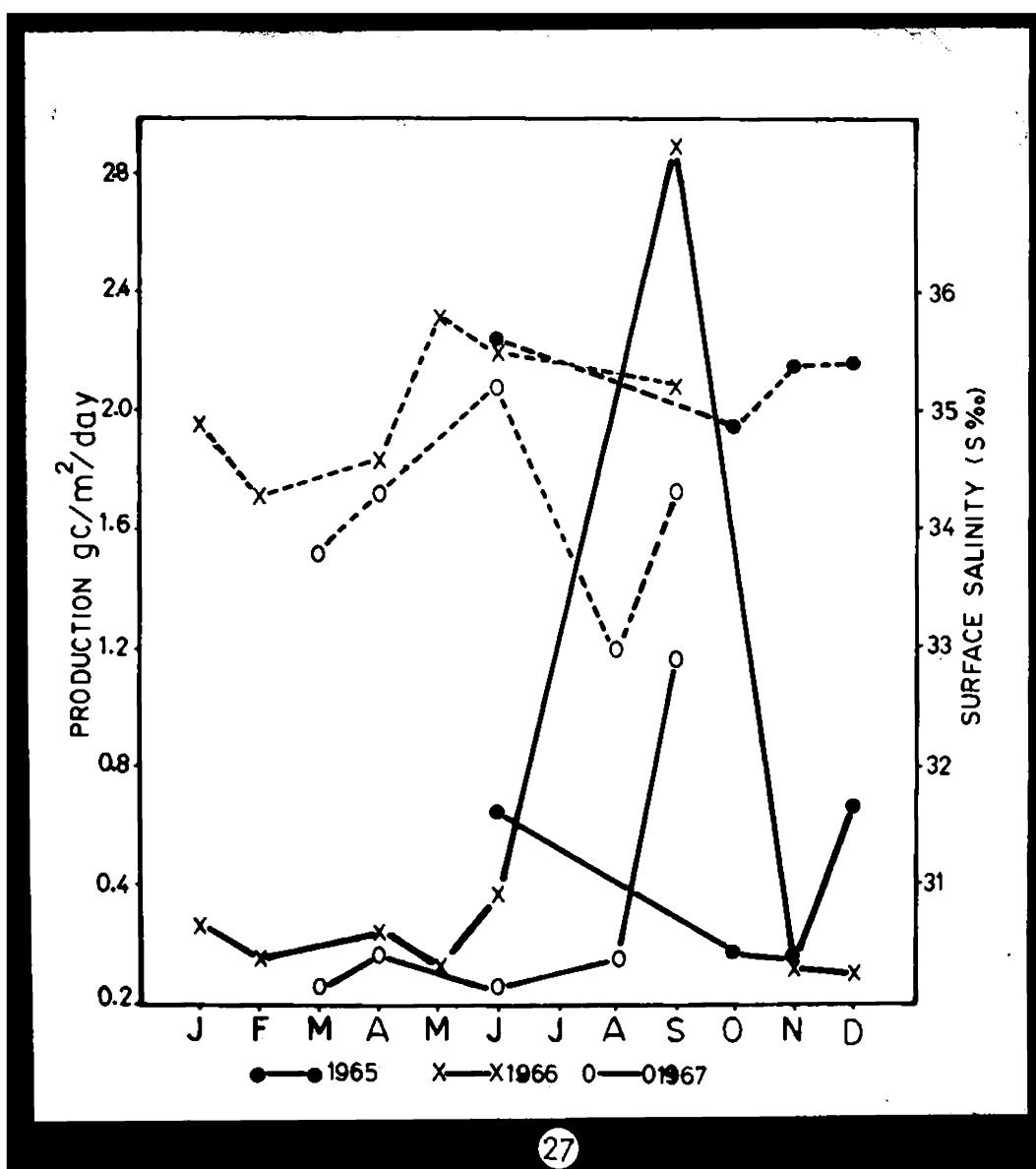
The phenomenon of upwelling on the west coast has also a pronounced effect on the replenishment of nutrients and thereby on primary production. The maximum effect of upwelling can be observed in the surface layers only when the deepest possible water enters the surface layers and also after a period ^{of} its presence. The time lag between replenishment and phytoplankton production is reflected in the spatial and temporal variation in the flowering of the diatoms. On the Trivandrum coast (about 8°30'N) diatoms gradually increase from January reaching the maximum in May (Menon, 1945; Hair, 1958). At Calicut the peak of the bloom, judged by the cell numbers is attained either in June or July when the monsoon is most active (Subrahmanyam, 1959). In the shallow areas of the Gulf of Mannar and Palk Bay the variation is not so much as the waters are mixed to the bottom and the phytoplankters have access to the nutrients in the water column and also what is generated from the bottom.

It may be seen from Figs. 26 and 27 that seasonal variation in salinity is not of direct importance on the rate of organic production though in a tropical estuary near Cochin many phytoplankters were found to bloom at exceptionally low salinities. Qasim, Bhattachari and Devassy (1972) who studied the behaviour of certain phytoplankters isolated from the estuary remark that

Fig.26. The seasonal trend in primary production in the Gulf of Mannar plotted against the common hydrographic properties. The values are only for the reference station during one year of observation. — Primary Production.



**Fig.27. The rate of primary production ($\text{gO}/\text{m}^2/\text{day}$)
for three years plotted against the respective
salinity (‰)values on the west coast.**



the adaptation for maximum photosynthesis in response to low salinity is to ensure their peak production during a time when high concentration of nutrients are available in the environment.

The temperature also though does not exhibit any direct relation (Fig. 26) has an indirect influence on the rate of primary production through regeneration of nutrient salts. According to Steemann Nielsen and Aabye Jensen (1957) the reason for the high rate of primary production in the shallow regions of the tropics is that the high temperature at the top of the bottom sediments causes a high regeneration of the nutrient salts which by diffusion and other mechanisms are transferred into the water layers above that brings forth an immediate effect on the production by phytoplankton.

In the offshore waters of the west coast on the other hand, it is the inter-relationship of the euphotic zone and mixed layer that determines the rate of production. As mentioned before, the depth of the mixed layer during pre-monsoon period is about 60 m which becomes less than 20 m during the monsoon period. During the post-monsoon period it deepens to 40 m. The euphotic zone in these regions is never more than 50-60 m. In the pre-monsoon period as there is no further admixture of nutrient-rich water the rate of production is maintained at a

lower level till the commencement of upwelling. During the post-monsoon period when the mixed layer deepens the nutrients have not been depleted and hence moderately high production continues during this period.

Steele (1956) associates differences in production for the Fladen Ground in the northern North Sea as a whole from year to year, as well as differences between one area and another, chiefly to variations in mixing which act as a brake on production. Ketchum et al. (1958) have also emphasized the great importance of vertical mixing and of regeneration in supplying nutrients for primary production. The lower rate of primary production during the pre-monsoon and the higher rates during monsoon and post-monsoon periods as well as the lower values observed seaward are thus accounted directly to the availability of nutrients.

The magnitude of annual primary production (gross) obtained in the present study along with some values from different regions and ecosystems are presented in Table 21 for comparison.

Table 21. Annual primary production in certain marine and estuarine environments

| Locality | | Production μg/m ² /year | Reference |
|---|-------|---------------------------------------|---------------------------------|
| Barents Sea | .. | 170-330 | Kreps and Verjbin-skaya, 1932 |
| English Channel | .. | 60-98 | Cooper, 1933 |
| Georges Bank | .. | 309 | Riley, Stommel and Bumpus, 1949 |
| North Sea | .. | 57-82 | Steele, 1956 |
| Long Island Sound | .. | 470 | Riley, 1956 |
| Off Hawaii (open ocean) | .. | 21 | Dety and Oguri, 1956 |
| Off Hawaii (inshore) | .. | 123 | .do- |
| Turtle grass bed (Florida) | 4,650 | | Odum, 1956 |
| Hawaiian coral reef | .. | 2,900 | Kohn and Helfrich, 1957 |
| Shelf waters off New York | | | |
| Shallow coastal region | | 160 } | |
| Continental slope | | 100 } | Ryther and Yentsch, 1958 |
| North Central Sargasso Sea | | 78 | .do- |
| Temperate Oceans | | 100-150 | Strickland, 1965 |
| Equator | .. | 110-146 | .do- |
| Barren tropical oceans | .. | 50 | .do- |
| Cochin Backwater (India) | | 281 | Qasim et al., 1960 |
| East coast (Continental shelf) | 230 | | Hair et al., 1968 |
| West coast of India (within 50 m depth) | | 453 | Present study |
| Gulf of Mannar (inshore Average 6 m depth) | | 400 | Present study |
| Palk Bay | | 561 | Present study |

PHOSPHORUS FRACTIONS IN GULF OF MANNAR AND THEIR
RELATION TO PRIMARY PRODUCTION

Phosphorus exists in sea water as dissolved inorganic phosphate, dissolved organic phosphorus compounds and particulate phosphorus as represented by plankton and detritus, as also by insoluble and adsorbed phosphates in suspension. Inorganic phosphate and total phosphorus determinations on a sea water sample before and after filtration will allow the estimation of the different fractions of phosphorus. Particulate phosphorus is found as the difference between the estimations of the unfiltered and filtered samples and the dissolved organic phosphate as the difference between the values for the total filtered sample and for the inorganic fractions.

The work of Redfield *et al.* (1957) in the Gulf of Maine and of Armstrong and Harvey (1950) in the English Channel provide the basic information of the three fractions of phosphorus-containing materials in the sea.

In India investigations on the seasonal variations in the phosphate content of the coastal waters have been conducted by Jayaraman (1951) and Ramamurthy (1953) at Madras, Jayaraman (1954) in Gulf of Mannar and Palk Bay, George (1953), Rao (1957) and Subrahmanyam (1959) at Calicut and by Reddy and Sankaranarayanan (1966)^b for the shelf waters of the Arabian Sea. Besides, Seshappa and Jayaraman (1956)

have studied the phosphates in the mud banks at Calicut and Qasim et al. (1969) in the Geochin backwaters. Extensive phosphate determinations over the Arabian Sea have been carried out during the IIOE recently; even prior to this, DANA, DISCOVERY and GALATHEA Expeditions had measured the distribution of phosphates in the Indian Ocean (Clowes, 1938; Steemann Nielsen and Aabye Jensen, 1957). However, the pattern of the relative changes in the three fractions has not yet been studied.

As the greatest change in the three fractions of phosphorus takes place in the surface waters, samples collected from the surface in Gulf of Mannar were analysed as part of the primary production studies. Duplicate samples of 'light' and 'dark' bottles were also analysed after a twenty four hour period of in situ incubation. The method for the determination of inorganic phosphate was that of Robinson and Thompson (1948) and for total phosphorus perchloric acid digestion method of Hansen and Robinson (1953). The optical density was measured by a Hillger and Watts Spekker Absorptiometer with a red filter and the values were derived from calibration curves constructed with known standards. The values of the various fractions in the initial samples are given in Table 22.

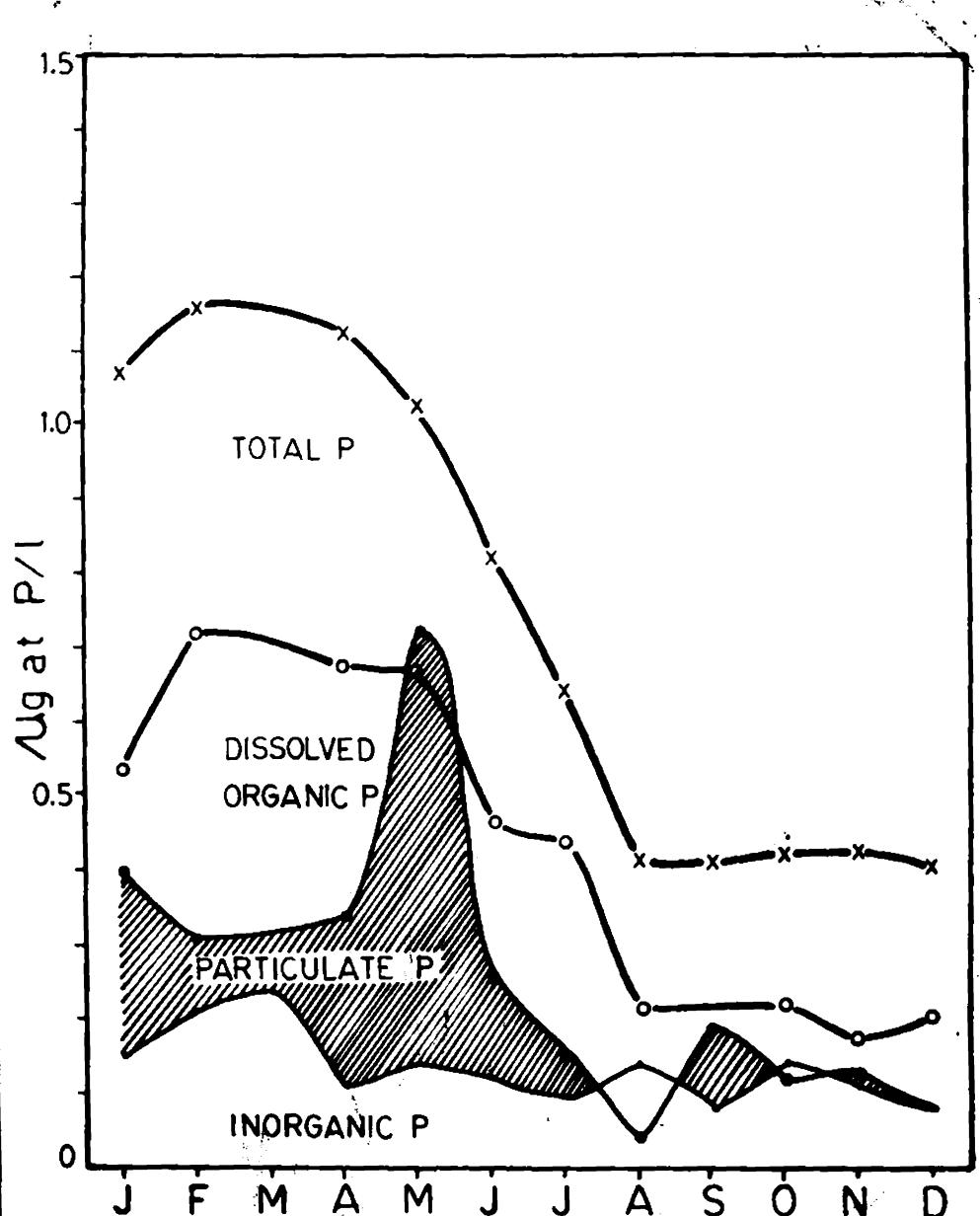
The inorganic phosphate values were relatively low in Gulf of Mannar and did not show much seasonal variation. The

monthly average values varied from 0.08 to 0.29 $\mu\text{g}.\text{at.P/1}$. The earlier investigations of Jayaraman (1954) also showed a similar pattern and magnitude. The peak value was seen in March with minor peaks in May, August and October. The total phosphorus, dissolved organic phosphate and particulate phosphorus, on the other hand, showed well-marked seasonal variation (Fig.18), though the magnitude of all the fractions was still of a lower order compared to that of the waters in the higher latitudes.

The total phosphorus remained over 1 $\mu\text{g}.\text{at.P/1}$ from January to May, between 0.5 and 1.0 $\mu\text{g}.\text{at.P/1}$ from May to July and at about 0.4 $\mu\text{g}.\text{at.P/1}$ for the rest of the year.

The same trend has been observed for the dissolved organic phosphate also which showed values $>0.5 \mu\text{g}.\text{at.P/1}$ between January and May. From August to December it remained at the lowest level of 0.2 $\mu\text{g}.\text{at.P/1}$. The bulk of the phosphorus content in the Gulf waters thus appears to be in dissolved organic form, the percentage distribution being over 50% on the average. It has been found to exceed 70% at times and only in one instance it had been reduced to less than 20%. Rao (1957) has found that organic phosphorus formed 63-91.5% of the total phosphorus except in June when the south-west monsoon caused stirring up of sediment, which resulted in relatively less organic phosphate in solution.

Fig. 28. Seasonal changes in the different phosphorus fractions in Gulf of Mannar (initial samples - surface)



The particulate phosphorus, the dominant fraction next to dissolved organic P, was available in varying proportions from January to July and September to November with the maximum values in May (ca. 0.85/ag.at.P/1). In fact, only during May the percentage contribution of particulate phosphorus as well as its magnitude exceeded that of the organic phosphorus fraction. This is presumably because of the high phytoplankton production (300-400 mg C/m³/day in the surface waters) during this period. Because of the nature of sampling it is unlikely that zooplankton organisms would have contributed to this fraction. So it is likely that the particulate phosphorus values obtained in this study were predominantly contributed by the phytoplankton and to a lesser extent possibly by detritus.

The inorganic fraction remains for the most part of the year at a low level of 12-15%. In March during the peak period it formed about 36%. The highest percentage contribution, however, was in August when it even formed 40% of the total at a time. The particulate phosphorus on that occasion was nil.

The trend for the three fractions is seen to persist in the 'light' and 'dark' bottles at the end of the experimental period of twenty four hours (Figs. 29 and 30) when oxygen measurement was taken to estimate the gross primary production, except in March-April which is the period of

Fig.29. Seasonal changes in the different phosphorus fractions in samples from Gulf of Maxmar after incubation in light bottles for 24 hours in situ.

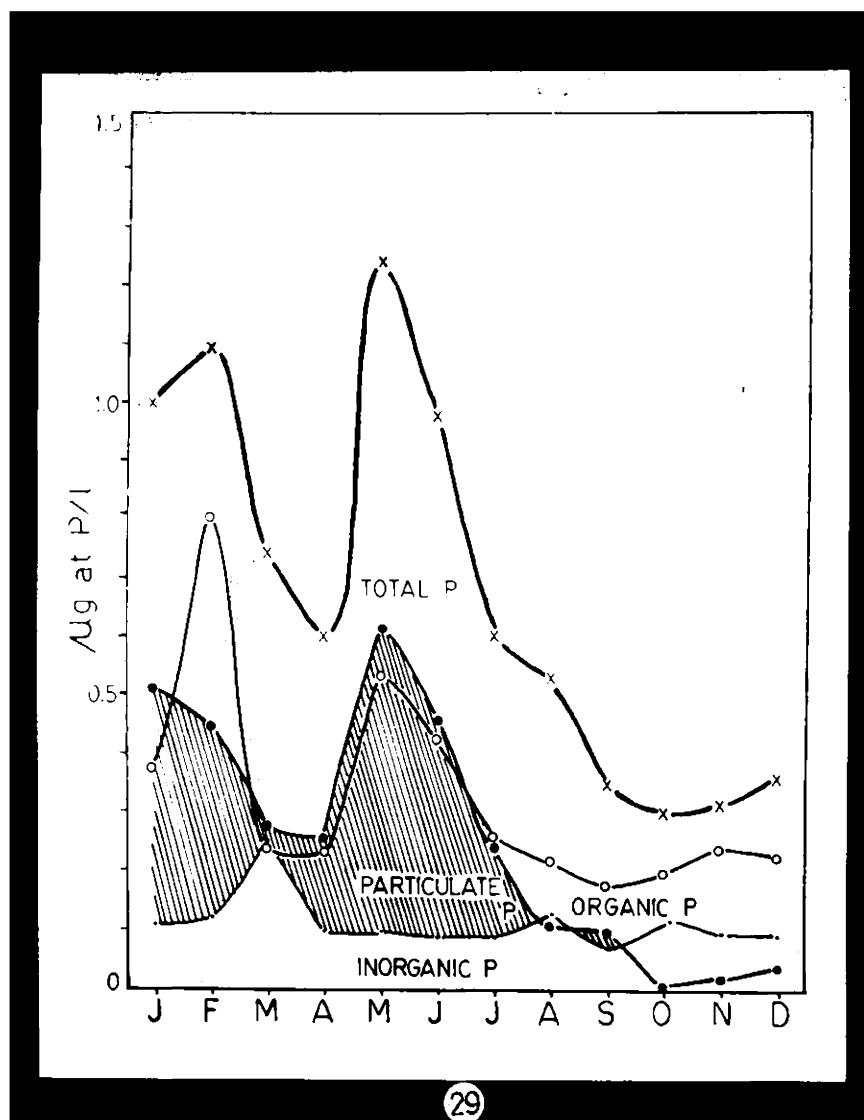
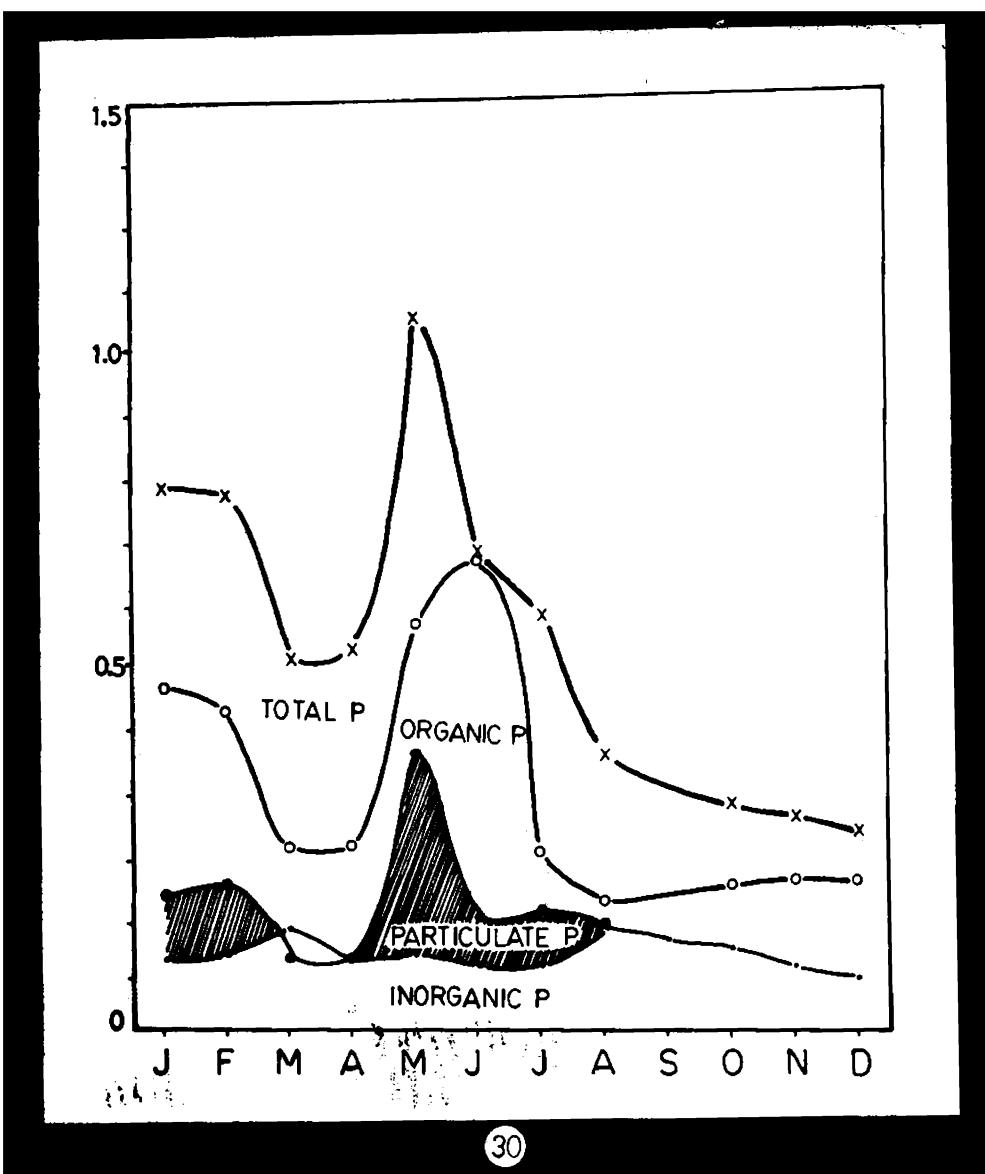


Fig. 30. Seasonal changes in the different phosphorus fraction in samples from Gulf of Mannar after incubation in dark bottles for 24 hours in situ.



zooplankton peak and excessive grazing of the phytoplankton. The 'dent' observed in the particulate fraction at the time could probably be the effect of grazing of the enclosed population. At all other times a consistent increase of phytoplankton cells was observed in the light bottles which accounts for the increase in the particulate fraction as compared to that of the dissolved organic fraction.

While discussing the comparatively lower level of phosphate in Gulf of Mannar combined with the absence of marked seasonal cycles, Jayaraman (1954) had speculated whether this indicated a low level of organic production too in these waters. However, he had also stressed the contention of Delman (1939) that probably the more rapid metabolism in the tropical seas would check such an accumulation of nutrients as usually occurs in most northern waters during the winter. A high rate of photosynthesis in the surface water all through the year requires a considerable amount of nutrients. As shown by Ketchum (1947), it is the replenishment and not the instantaneous concentration which determines the fertility of an aquatic environment.

The regeneration of phosphate could be measured indirectly i.e. roughly 1 mgP is assimilated for every 40 - 50 mgC (Steemann Nielsen and Aabye Jensen, 1957). The

values of organic production at this station for the period varied between $124 \text{ mgC/m}^3/\text{day}$ in July to $388 \text{ mgC/m}^3/\text{day}$ in April with an annual mean of $202 \text{ mgC/m}^3/\text{day}$ (Prasad and Hair, 1963). So the daily phosphate assimilation may be assumed to be about $4 \text{ mg/m}^3/\text{day}$ ($0.13 \mu\text{g.at.P/l}$) which is about the average quantity available in solution. The inorganic phosphate in solution at any moment in a water mass may represent from 1 to 500 per cent of the amount taking part in the daily metabolism (Steemann Nielsen, 1951).

It may thus be seen that the amount of phosphate assimilation in the shallow waters of Gulf of Mannar is almost equal to the instantaneous concentration of the inorganic phosphate. As the water masses are without stratification throughout the year and are in constant contact with the bottom, the regeneration of phosphate taking place at the bottom is constantly utilised by the phytoplankton at almost the same rate. The speed of regeneration from the shallow bottom seems to be high enough to maintain the phosphate at a constant level.

Table 22. Seasonal distribution of the three phosphorus fractions at the surface in the Gulf of Mannar during the different months

| Total P mg.at./l. | Inorganic P mg.at./l. | I.P. % | Organic P mg.at./l. | O.P. % | Parti- culate P,ug. at./l. | P.P % |
|----------------------|--------------------------|-----------|------------------------|-----------|-------------------------------------|----------|
| 0.63 | 0.12 | 19.1 | 0.36 | 57.1 | 0.15 | 23.8 |
| 0.81 | 0.10 | 12.3 | 0.51 | 63.0 | 0.20 | 24.7 |
| 1.76 | 0.22 | 12.5 | 0.69 | 39.2 | 0.85 | 48.3 |
| 1.06 | 0.10 | 9.4 | 0.46 | 43.4 | 0.50 | 47.2 |
| 1.71 | 0.14 | 8.2 | 1.09 | 63.7 | 0.48 | 28.1 |
| 0.96 | 0.28 | 29.2 | 0.59 | 61.4 | 0.09 | 9.4 |
| 0.94 | 0.11 | 11.7 | 0.72 | 76.6 | 0.11 | 11.7 |
| 0.63 | 0.24 | 38.1 | 0.32 | 50.8 | 0.07 | 11.1 |
| 0.87 | 0.10 | 11.5 | 0.65 | 74.7 | 0.12 | 13.8 |
| 0.63 | 0.11 | 17.4 | 0.49 | 77.7 | 0.03 | 4.9 |
| 1.88 | 0.13 | 7.0 | 0.90 | 47.8 | 0.85 | 45.2 |
| 1.15 | 0.18 | 15.7 | 0.38 | 53.0 | 0.59 | 51.3 |
| 2.09 | 0.18 | 8.6 | 1.07 | 51.2 | 0.84 | 40.2 |
| 0.59 | 0.09 | 15.3 | 0.42 | 71.3 | 0.08 | 13.4 |
| 1.13 | 0.13 | 11.5 | 0.49 | 43.4 | 0.51 | 45.1 |
| 0.79 | 0.15 | 19.0 | 0.60 | 76.0 | 0.04 | 5.0 |
| 0.78 | 0.09 | 11.5 | 0.32 | 41.1 | 0.37 | 47.4 |
| 0.92 | 0.05 | 5.4 | 0.57 | 62.0 | 0.30 | 32.6 |
| 0.62 | 0.14 | 22.6 | 0.42 | 67.7 | 0.06 | 9.7 |
| 0.56 | 0.15 | 26.8 | 0.41 | 73.2 | - | - |
| 0.51 | 0.14 | 27.4 | 0.25 | 49.1 | 0.12 | 23.5 |
| 0.23 | 0.11 | 47.8 | 0.12 | 52.2 | - | - |
| 0.35 | 0.14 | 40.0 | 0.17 | 48.6 | 0.04 | 11.4 |
| 0.41 | 0.08 | 19.5 | 0.14 | 34.2 | 0.19 | 46.3 |
| 0.56 | 0.12 | 21.4 | 0.22 | 39.3 | 0.22 | 39.3 |
| 0.37 | 0.12 | 32.4 | 0.23 | 62.2 | 0.02 | 5.4 |
| 0.34 | 0.11 | 32.4 | 0.19 | 55.9 | 0.04 | 11.7 |
| 0.31 | 0.11 | 35.5 | 0.06 | 19.3 | 0.14 | 45.2 |
| 0.56 | 0.11 | 19.6 | 0.26 | 46.4 | 0.19 | 34.0 |
| 0.34 | 0.08 | 23.5 | 0.20 | 58.8 | 0.06 | 17.7 |
| 0.72 | 0.15 | 20.8 | 0.41 | 57.0 | 0.16 | 22.2 |

THE TOTAL ORGANIC NITROGEN IN PARTICULATE MATTER AS
AN INDEX OF PRIMARY PRODUCTION IN THE
GULF OF MEXICO

The circulation of nitrogen in the sea is based on the quantitative relationships involved in the various steps of the nitrogen cycle viz., living organisms, dead organisms, ammonia, nitrite, nitrate, living organisms. Among these the soluble substances have received considerable attention and a lot of information has been accumulated concerning their quantitative occurrence in various seas, seasonal fluctuations and their influence on the plankton production.

The determination of protein from total cell nitrogen of phytoplankton by multiplication with a conversion factor of 6.25 is a standard practice and is considered satisfactory for most field work (Strickland, 1965). However the nitrogen present in the plankton and its seasonal variation has not received much attention. Though attempts have been made to calculate nitrogen occurring in the organisms from nitrate data it has not met with success. The movements of the water masses and the turnover of the organisms make it impossible to determine the amount of nitrogen present in the particulate matter in any part of the sea at a given moment from nitrate data taken at intervals of several

weeks or months. Hence a micro-technique for the determination of organic nitrogen in sea water and plankton was used by Ven Brand (1935). This study involves the determination of protein from kjeldahl nitrogen in combination with a sedimentation technique normally used for the counting of phytoplankton in order to assess how far these values represent the standing crop.

One litre of water collected at the same time along with the samples for oxygen and also samples from light and dark bottles after twenty four hours were treated with 40 ml of 40% of Na_2SO_3 solution. They were shaken well and after half an hour filtered through fluted filter paper. The precipitates were then washed with several changes of distilled water. Afterwards the precipitates were washed into centrifuge tubes and centrifuged at 3000 r.p.m. The precipitates were further centrifuged with two or three changes of distilled water and were then transferred to kjeldahl flasks. 2 ml of concentrated sulphuric acid and a pinch of $\text{K}_2\text{S}_2\text{O}_8$ - CuSO_4 mixture were then added and then digested. After cooling it was taken up with distilled water and ammonia estimated in a microkjeldahl in the presence of excess NaOH . Blanks were also run along with all the analyses and corrections made. Altogether 47 analyses were conducted spread over an eighteen-month period.

The values of nitrogen were converted into protein by multiplying with the factor 6.25.

Table 23 gives the mean values obtained for each month with the corresponding values for primary production.

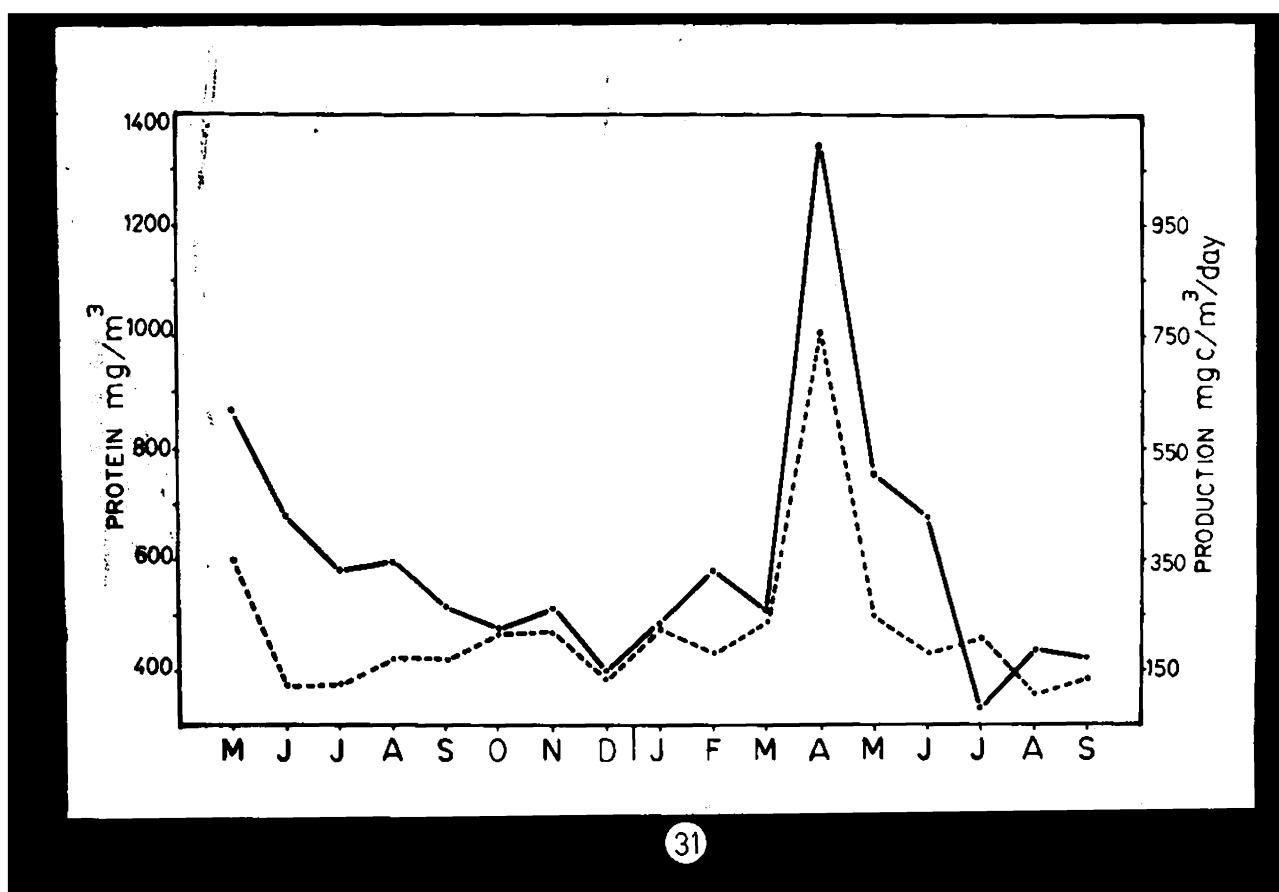
Table 23. Monthly variations of values of protein ($N \times 6.25$) in particulate matter and primary production from the surface and bottom samples of Gulf of Mannar.

| Period | Surface | | Bottom | |
|--------------------|------------------------------|-------------------------|------------------------------|---|
| | Protein mg/m ³ | Primary pro- duction | Protein mg/m ³ | Primary pro- duction mg/m ³ /day |
| <u>1959</u> | | | | |
| January | 475.00 | 227.90 | 647.00 | 387.00 |
| February | 685.94 | 177.37 | 657.33 | 232.33 |
| March | 506.25 | 235.07 | 647.33 | 41.66 |
| April | 1350.00 | 761.10 | 946.33 | 757.66 |
| <u>1958</u> | | | | |
| May | 875.00 | 350.45 | 1006.00 | 197.50 |
| June | 679.69 | 117.71 | 621.00 | 114.00 |
| July | 587.50 | 123.84 | 671.80 | 142.80 |
| August | 597.92 | 170.57 | 594.60 | 67.66 |
| September | 518.75 | 170.57 | 656.00 | 120.00 |
| October | 479.17 | 216.43 | 489.66 | 90.33 |
| November | 512.50 | 220.37 | 726.00 | 76.50 |
| December | 379.92 | 147.63 | 818.33 | 578.33 |

It is found that the trend in primary production is reflected in the values for protein obtained by this method. Both peaks coincide in April for the surface water (Fig.31). The individual values from all the analyses of the surface water ranged from 125 mg to 1450 mg per m^3 with the corresponding primary production being 60 and 760 mg/ m^3 /day. The trend was almost similar for the bottom water also but much lower values were obtained from the bottom samples. Disproportionately large values for protein against primary production were obtained occasionally which could be either due to detritus or stray occurrence of zooplankters. However the mean values of both parameters showed a significant correlation at 5% level: the correlation coefficient being 0.3 for the surface and 0.36 for the bottom (Fig.32).

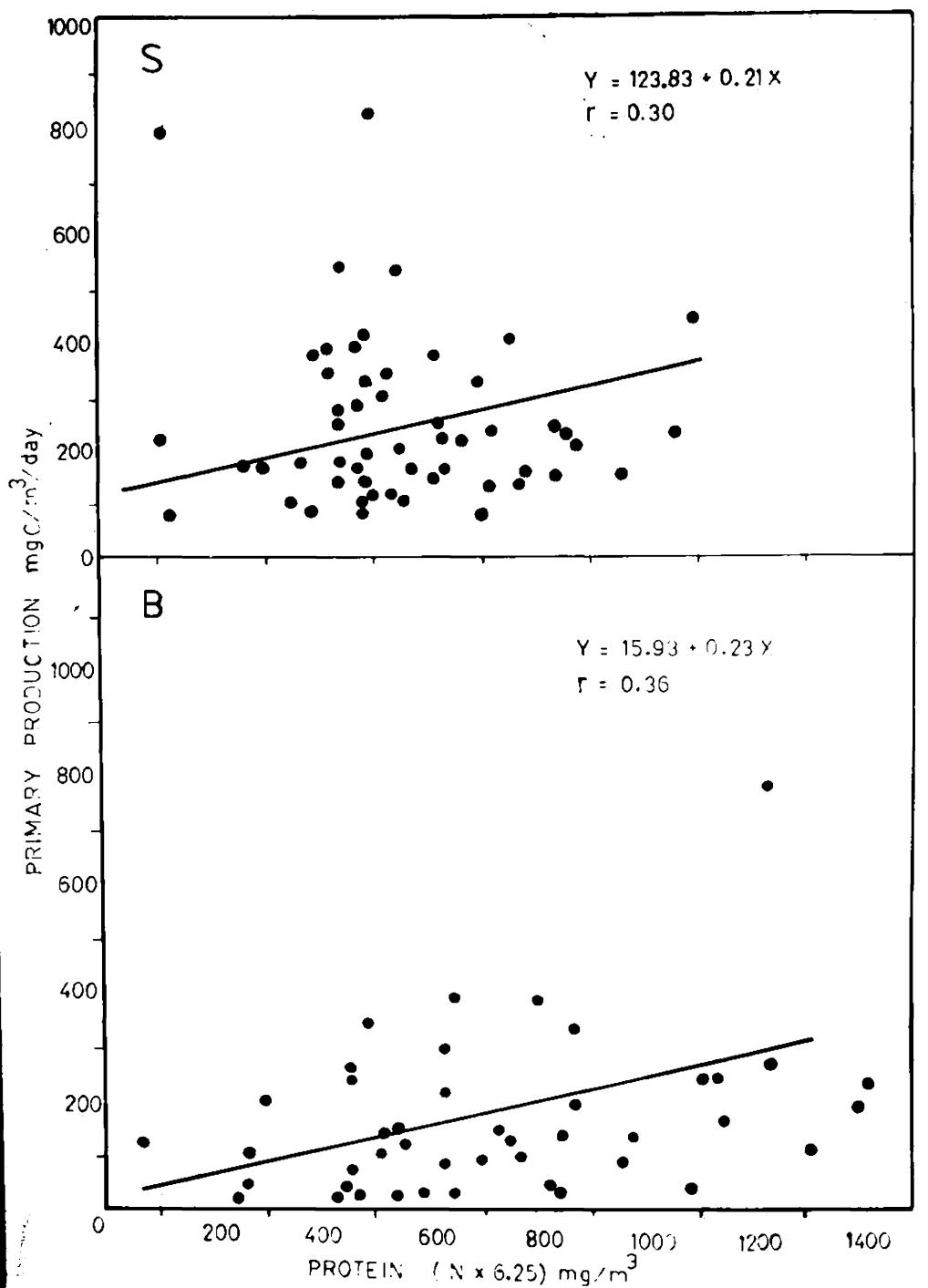
The estimation of total nitrogen in the particulate matter has certain obvious difficulties. As the amount of plankton in a sample of water is very small in comparison with dissolved organic matter it is not possible to determine the nitrogen content of the plankton by subtraction of the nitrogen content in a certain amount of filtered water from that of the same water without filtration. As particulate nitrogen occurs in planktonic algae and animals, bacteria and detritus, the contribution of any one of

Fig.31. Seasonal variation of protein ($\text{N} \times 6.25$) and primary production in the surface waters of the Gulf of Mannar during the period 1959 to 1969. Dashed line - primary production and continuous line - protein.



(31)

Fig.32. Relationship between protein in particulate matter and primary production. S - surface samples and B - bottom samples.



these categories is difficult to evaluate because of non-uniformity as to shape, number and particle size-distribution. Besides the nitrogen content of phytoplankton varies widely according to the state of nutrition of the cells.

Attempts to make a more direct routine estimate of protein have been undertaken by Krey (1951) and Strickland and Parsons (1960). The Krey method gives a certain differentiation between living matter and less reactive detritus. Steemann Nielsen (personal communication) also favours the Krey method than Kjeldahl nitrogen method as the measure of an index of productivity.

Tentsch and Vaccaro (1958) have suggested that nitrogen may be estimated indirectly from a knowledge of the carotenoid chlorophyll a content of a phytoplankton crop. But this work applies only to culture and it has not been fully substantiated under natural condition with mixed population. Thus it is not certain that all forms of nitrogen are measured by the Kjeldahl technique. Discrepancies that are sometimes observed lead one to suppose that some nitrogen may be missed or that substantial amounts of non-protein nitrogen may occur in certain samples (Tentsch and Vaccaro 1958, McAllister et al. 1961, Parsons et al. 1961). McAllister et al. (loc.cit.) reported a considerable discrepancy between the amount of protein

obtained by the kjeldahl method ($N \times 6.25$) and protein determined as casein. Hence, apart from serving as a crude index of standing crop, the total nitrogen values do not seem to hold much promise as an index of productivity.

PRIMARY PRODUCTION OF THE WORLD OCEANS AS COMPARED
TO THAT OF THE INDIAN SEAS

During the last two decades several expeditions have collected extensive data from different parts of the world oceans. In addition, through individual efforts intensive data from many isolated regions have also been obtained. The first estimate of the primary production of the world oceans made by Riley (1944) was found to be 10 times higher by Steemann Nielsen after a round the world trip of GALATHEA (Steemann Nielsen and Aabye Jensen, 1957). Several attempts made subsequently at an evaluation of the world primary production indicated that the seas are not more productive than land and the magnitude is only because of the larger area. Recently Koblenz-Mishke et al. (1970) have reviewed the production of organic matter for the world oceans and get the figure which almost coincides with that of Steemann Nielsen's estimate. According to these authors the world production is $2.5 - 3.0 \times 10^{10}$ tons of carbon per year (gross) and $1.5 - 1.8 \times 10^{10}$ tons of carbon (net) is a more accurate figure. Gulland (1970) while assessing the fish resources of the world oceans has given a brief account of the primary production of the different regions. Cushing (1971)

has estimated the total production in some of the upwelling regions of the world. Thus from the existing literature it is possible to derive a general idea of the magnitude of primary production in all the oceans.

Atlantic Ocean

Studies on primary production have been made by a large number of authors using a variety of methods in different parts of the Atlantic especially the north-eastern region. According to Steele (1965) the annual production is in the range of $50-150 \text{ gC/m}^2/\text{year}$ while Cushing considers the possible range as $40-200 \text{ gC/m}^2/\text{year}$. Assuming an average figure of $100 \text{ gC/m}^2/\text{year}$, Gulland (1970) has given a figure of 55×10^6 tons of carbon fixation for the north-east Atlantic.

During the survey of GALATHEA the highest rate of $3.8 \text{ gC/m}^2/\text{day}$ and the lowest rate of $0.043 - 0.058 \text{ gC/m}^2/\text{day}$ were observed in the Atlantic (Walvis Bay and Sargasso Sea respectively). The region of Benguela Current was found to be one of the most productive regions with a daily rate of $0.46 - 2.5 \text{ gC/m}^2/\text{day}$. In the Central part off the west coast of Africa the main areas of high production are the upwelling regions and oceanic areas along the equator. According to the seasonal variations in the rate of upwelling the rate of primary production also varies with

the peak values reaching $5.2 \text{ gC/m}^2/\text{day}$ off Dakar. Outside the peak season the rates fall to $0.2 - 0.4 \text{ gC/m}^2/\text{day}$ (Steemann Nielsen and Aabye Jensen 1957; Serekin and Kliashterin 1961; Bessonov and Fedorev 1965). Off the coast of South America measurements have been made by Teixeira and Tundisi (1967). They have reported high values towards the coast decreasing seaward. In July/August higher values were found in the open ocean. El Sayed (1966) reported higher primary production off the Argentinean Coast than in Drake Passage and Weddel Sea. According to Mandelli and Orlando (1966), the Falkland Current is amongst the most productive area of the world oceans and also carries a permanent high phytoplankton biomass. The estimate of annual primary production in the Falkland Current is more than $200 \text{ gC/m}^2/\text{day}$ in the central part between 40° and 44°S and less than half as much in the southern parts (Gulland op.cit.)

The mean value given for the Atlantic by Koblents-Mishke et al. (1950) is $190 \text{ mgC/m}^2/\text{day}$ and $69.4 \text{ gC/m}^2/\text{year}$, for the Atlantic Ocean, which would amount to a net production of ca 5×10^9 tons per year. Of this the Benguela upwelling region alone accounts for 375 million tons of C/year which is a very high figure compared with those for other upwelling areas and bigger than the estimate for

the Peru/Chile upwelling area (Cushing, 1971). Outside the upwelling areas rate of primary production is at the moderate level typical of subtropical waters i.e., around 50 gC/m²/year (Gulland, 1970).

Primary production in the Mediterranean and Black Sea is generally low, but moderately high in some parts, especially in the Black Sea. Values for the Adriatic Sea also is high with 120 - 364 gC/m²/year.

Pacific Ocean

Koblents-Nishke (1965 and 1967) has reviewed the data on primary production from the Pacific Ocean. A band of high primary production with rates between 100 and 150 gC/m² extends along the North American coast to the tip of the Alaskan Peninsula and along the Aleutian Island chain including much of the offshore area of the Gulf of Alaska. The open oceanic part of the North Pacific is also noticeably more productive (50-100 gC/m²/year) than the tropical and subtropical areas. The Puget Sound has a very high rate of 200-400 gC/m²/year. On an average of 150 gC/m²/year for the coastal strip, within 500 m contour the total annual primary production has been computed at 54 million tons (Gulland, op.cit.). Over 600 gC/m²/year has been found in the south-eastern part of the Bering Sea (Ivanenkov, 1961). In the north-west Pacific highest

production rate of $5 \text{ gC/m}^2/\text{day}$ was recorded east of Hokkaido within the zone of convergence of warm and cold water. Taniguchi (1972) has calculated $89 \text{ gC/m}^2/\text{year}$ in the Bering Sea, $156 \text{ gC/m}^2/\text{year}$ in the Oyashio Current and $48 \text{ gC/m}^2/\text{year}$ in the Kuroshio Counter Current. The North Equatorial Current showed the lowest rate of $33 \text{ gC/m}^2/\text{year}$. The waters of the South Equatorial Current ($106 \text{ gC/m}^2/\text{year}$) and the region east of New Zealand ($156 \text{ gC/m}^2/\text{year}$) were found to be more productive.

In the south-east Pacific, Galland (1970) quotes Strickland, Eppley and Rojas de Mandiola that the annual production near the coast of Peru is more than $200 \text{ gC/m}^2/\text{year}$ but suspect that the value will be considerably higher, possibly of the order of $500 \text{ gC/m}^2/\text{year}$. This could be in view of the recent measurement by Ryther et al. (1971) in a packet of newly upwelled water in the Peru Current of an average rate of $10 \text{ gC/m}^2/\text{day}$ for five days. Cushing's estimate of total primary production in the Peru Current upwelling is 155 million tons of carbon of which about 45 million tons were estimated to be produced off Chile and the remainder off Peru. The average value for the Pacific Oceans as given by Koblenz-Mishke et al. (1970) is $127 \text{ mgC/m}^2/\text{day}$ and $46.4 \text{ gC/m}^2/\text{year}$. According to these authors the Pacific Ocean is the least productive of all the oceans,

whereas the Indian Ocean is the most productive. At the same time the yield ratio is considerably lower as compared to the Atlantic and Pacific Oceans. The potential yield in relation to primary production in the Indian Ocean and adjacent seas is discussed in the next section.

INDIA AND THE INDIAN OCEAN FISHERIES

India has a long coast line of nearly 6,000 km with the Andaman and Nicobar Islands and the Laccadive Archipelago lying beyond her shores. The geographical position of India with the peninsular portion extending deep into the central part of the Indian Ocean gives her a locational advantage in marine fishing activities. At present though India contributes about 40% of the fish landings of the Indian Ocean, when viewed against the world production of 60 million tonnes of marine fish, her share is only about 1 million tonne representing less than 2%. A quarter of a million persons are actively engaged in actual fishing producing annual landings valued at Rs.1,200 million. The industry also provides employment to 1.4 million persons. There are about 10,000 mechanised crafts which land 30% of the total production. Over 600 million rupees worth of sea food is exported to different countries.

Studies made during the International Indian Ocean Expedition as well as those conducted in the bordering countries reveal that there are several areas in the Indian Ocean which are exceptionally rich in nutrients,

chlorophyll, organic production and zooplankton biomass. Consequently these areas could sustain large stocks of fish. This section deals with the present yield and its composition and the potential resources in the Indian seas and the Indian Ocean in general, as derived from productivity studies.

Topography

The Indian Ocean has an area of about 75 million square kilometres including Antarctica and some of the adjacent seas, as against 106 million sq.km for the Atlantic and 180 million sq.km for the Pacific Ocean. The shallow water areas form about 3.1 million sq.km in the Indian Ocean. The shelf areas vary in width as well as in surface contour.

The west coasts of India, Ceylon and Pakistan have prominent shelves, whereas on the east coast the shelves are narrow. The east coast of Africa has a narrow shelf except at the southern-most tip. The coastal regions of Mozambique, Tanzania and Kenya are fringed with mangrove and coral reefs. The coasts of Burma, Thailand and Malaysia have a wide shelf with mangrove swamps. The west coast of Australia has a narrow shelf which widens towards the north. The western Indian Ocean Islands have banks which are of

both volcanic and coral reef type. The availability of resources have thus to be viewed with the nature of the terrain for exploitation on a commercial scale.

Present yield and its composition

The fish landings in the Indian Ocean and the development during the last fourteen years as compared to the Atlantic and Pacific Oceans present a poor comparison both in the progress and also in the yield ratio in terms of primary production (Table 23).

Table 23. Fish landings during the past fourteen years and the present yield in terms of primary production for the different oceans

| Ocean | Fish Landings (Million tonnes) | | Present yield as percentage of primary production (both in %) |
|----------|--------------------------------|-------|---|
| | 1958 | 1971 | |
| Atlantic | 13.6 | 23.32 | 0.04 |
| Pacific | 13.4 | 33.53 | 0.03 |
| Indian | 1.4 | 3.06 | 0.0075 |

The pattern of development in the world fishing shows that at the beginning of this century the total landings were only 4 million tonnes. By 1913 it had doubled to 9.5 million tonnes and again doubled by 1938 to 20.5 million tonnes. The marine fish production increased at the rate of 4.5% per year from 1952 to 1958 and picked up speed thereafter. In spite of a small drop during 1968 and 1971 the average growth rate for the preceding ten years was 6.5% (Table 24).

Table 24. World production of fish and rate of increase during the last fourteen years.

| Year | World production of fish (in million tonnes) | Rate of increase |
|------|---|------------------|
| 1958 | 28.39 | 4% |
| 1959 | 31.41 | 10% |
| 1960 | 33.63 | 7% |
| 1961 | 36.77 | 9% |
| 1962 | 40.05 | 9% |
| 1963 | 41.70 | 4% |
| 1964 | 46.20 | 11% |
| 1965 | 46.50 | 1% |
| 1966 | 50.20 | 8% |
| 1967 | 53.16 | 6% |
| 1968 | 56.49 | 6% |
| 1969 | 54.91 | -2.8% |
| 1970 | 61.28 | 11.6% |
| 1971 | 60.55 | -1.2% |

This rate of increase is unparalleled by that for any other basic food commodity. Moreover, the future outlook is encouraging because according to the Indicative World Plan estimates, the world marine fish of currently exploited species with known techniques in areas already fished may amount to some 120 million tonnes by 1985. But the living resources of the sea are not limitless and higher yields will be possible only by envisaging utilisation of unconventional resources or aquaculture. The maximum yield in terms of carbon (which forms about 10% of the wet weight) is only 0.4% of the net primary production in the coastal

areas (Steemann Nielsen, 1952) and in the oceanic areas considerably less. When viewed in this light India and the Indian Ocean countries have a challenging task to bridge the gap between the present yield and the possible production. Panikkar (1967) has visualised an output of 20 million tons of fish per annum from the Indian Ocean towards the close of this century.

Out of the present yield of 3 million tonnes from the Indian Ocean, western region accounts for 1.9 million tonnes. The Arabian Sea provides 13,00,000 tonnes and Bay of Bengal 8,40,000 tonnes. The group of fishes consisting of herrings, sardines, anchovies and related forms contribute about 28% of the total catch from the Indian Ocean. Red fishes, basses and congers come next with 19% of the total yield. The crustaceans account for 12% of the average annual landings of which India's share at present is about 150,000 tonnes, consisting mainly of shrimps, Tunas, bonitos and skipjack account for 11% and the group consisting of mackerels, bill fishes, etc., account for 8.6%.

Primary production and potential yield

When primary production is considered in the overall role of food chain relation in the sea it becomes necessary to know the efficiency of energy transfer from one step in the food chain to another. This is one of the least known

aspects of the food chain dynamics in the sea. All food chains from phytoplankton herbivores and upwards tend to become intermeshed and forms a food web rather than a chain. Many organisms feed at more than one level of the food chain. When the steps are few in the food chain higher efficiencies of food energy transfer are obtained. The most important direct consumers of phytoplankton are the copepods and euphausiids. These crustaceans and their larvae constitute the bulk of the food of the other plankton animals including pelagic fish larvae and the plankton feeding fish. The most important plankton feeding group of fishes are the clupeoids which constitute about 30% of the marine fish catch. A small fraction of the production (1-10%) reach the bottom and serve as a food source for the bottom fauna.

It has been observed that the landing of commercial fish in intensely exploited waters is about 0.4% of the organic matter produced by the phytoplankton. Even though the percentage utilization does not seem to be high it is the highest that is found in the sea.

The data are now available from various sources on standing crop, primary production, chlorophyll values and exploratory fishing reports. Hence it is possible to make a broad appraisal of the potential resources.

The distribution pattern of chlorophyll in the Indian Ocean shows that the level of pigment concentration per unit

area is almost the same to that of Atlantic and Pacific Oceans even though the concentration per unit volume is slightly lower. (Humphrey, 1966).

The average amount of chlorophyll a for the entire Indian Ocean is found to be 14.81 mg/m^2 (integrated values upto 200 metres). For the west coast of India the integrated mean value is 25.41 mg/m^2 while for the east coast it is only 8.24 mg/m^2 . In the western Indian Ocean during the south-west monsoon extremely high values are found mainly in the area off Cape Guardafui and Socotra in the upwelling regions associated with Somali current. High values of primary production and neoplankton biomass are also observed in this area. (Prasad, 1969; Prasad, Banerji and Nair, 1970). Laird, Breivogel and Yentsch (1964) observe that in terms of potential fisheries, the high chlorophyll values along the Somali coast are of interest. The productivity of such areas in terms of carbon fixed per square metre per day is about 4-5 grams. If the rate of production is steady during the monsoon period the total production would be about $350-450 \text{ g/m}^2$. In terms of dry weight of algae it amounts to 800 g/m^2 which ranks this area among the most productive. Hence the authors believe that the area off the Somali coast, longitude 57°E between latitude 10°N and the equator could support excellent fisheries during the

south-west monsoon period.

There is great amount of spatial variation in the magnitude of primary production in the Indian Ocean. The shelf areas which sustain the bulk of the fish production at present are on the whole having a high rate of production. Because of the constant replenishment of nutrients in the surface layers the shallow water areas of the tropics are generally productive. An average rate of 0.5 to 1.0 gC/m²/day is observed in the shallow areas most of the time. Rates exceeding 2 gC/m²/day are found during the south-west monsoon.

In the eastern Arabian Sea towards the coast of India the average rate within 50 metre depth is about 1.2 gC/m²/day and for the outer shelf regions the rate is < 0.5 gC/m²/day. The net production (taken as 60% of the gross) for the shelf area on the west coast of India within 50 metres (114,520 sq.km) has been estimated as 30×10^6 tonnes of carbon. Between 50 and 200 metres (168,790 sq.km) the net production is only 16×10^6 tonnes. Thus for the whole continental shelf area on the west coast of India the annual net production is computed at 46 million tonnes of carbon.

Schaeffer (1965) has tried to estimate the potential harvest of the sea from net production of the world oceans by assuming different ecological efficiency factors obtained

experimentally by Slobodkin (1959). Accordingly the potential yield for the west coast of India at different trophic levels will be as given below:

Estimates of potential yield at various trophic levels (in tonnes)

| Trophic level | Ecological efficiency factor | | |
|----------------------------|------------------------------|------------------|--------------------|
| | 10% | 15% | 20% |
| | Total Carbon wt. | Total Carbon wt. | Total Carbon wt. |
| (0) Net primary production | 3×10^7 | 3×10^7 | 3×10^7 |
| (1) Herbivores | 3×10^6 | 3×10^7 | 4.5×10^6 |
| (2) 1st stage carnivores | 3×10^5 | 3×10^6 | 6.8×10^5 |
| (3) 2nd stage carnivores | 3×10^4 | 3×10^5 | 10.2×10^4 |
| (4) 3rd stage carnivores | 3×10^3 | 3×10^4 | 15.3×10^3 |

Since it is difficult to assign a proper trophic level to the different categories of fishes as they may belong to more than one trophic level, on assumption that if the harvest is all taken at step 3, the following will be the potential yield for the west coast of India for the various ecological efficiency factors:

| Ecological efficiency factor | Total biomass of fish (tonnes) |
|------------------------------|--------------------------------|
| 10% | 3,00,000 |
| 15% | 10,20,000 |
| 20% | 24,00,000 |

As the present yield is about thrice the figure at 10% level it may be considered that harvesting at stage 3 at 10% efficiency factor is too low. At 15% efficiency factor the biomass should be 1 million tonnes and at 20% efficiency 2.4 million tonnes. However, if it is assumed that half of the potential could be taken at step 2 as pelagic fishes which feed on phytoplankton or a mixture of phytoplankton and zooplankton and another half at step 3 which is more realistic (Schaeffer loc.cit.) the available potentials would be as follows:

| <u>Ecological efficiency factor</u> | <u>Total biomass of fish (tonnes)</u> |
|-------------------------------------|---------------------------------------|
| 10% | 16,50,000 |
| 15% | 39,10,000 |
| 20% | 72,00,000 |

Taking various factors into consideration such as depletion of stock from predation, economic viability etc., a potential harvest of at least 2 million tonnes from the west coast is a modest estimate (i.e. 50% of the biomass at 15% ecological efficiency).

The optimum yield from primary production in intensely exploited waters being 0.4%, the potential yield could be computed as $\frac{0.4 \times 46 \times 10^6}{700} = 184,000$ tonnes of carbon = 1.84 million tonnes of fish. The latest figure for 1971 being

904,400 tonnes there seems to be scope for doubling the present catch.

On the east coast the net production has been estimated at 15×10^6 tonnes. This may be an under estimate due to lack of sufficient data. But the shallow areas on the south-east coast being highly productive it is possible that a higher annual net production could be envisaged. So assuming as before that half is taken at steps 2 and 3 the potentials will be as follows:

| Ecological efficiency factor | Total biomass of fish (tonnes) |
|------------------------------|--------------------------------|
| 10% | 8,25,000 |
| 15% | 19,55,000 |
| 20% | 36,00,000 |

That amounts to 50% of the west coast production or 1 million tonnes instead of the present catch of 250,000 tonnes. Thus the potential harvest for the whole Indian coast is about 3 million tonnes of fish, which is about the yield from the Indian Ocean at present.

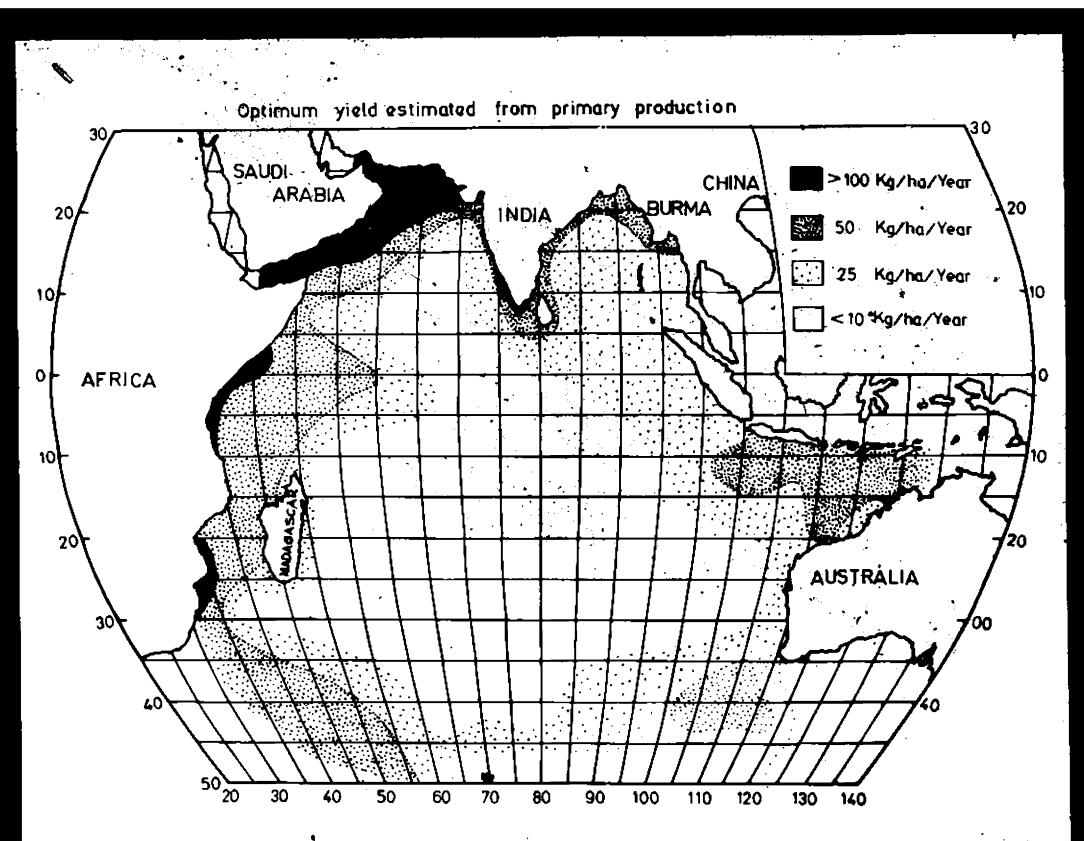
Prasad, Banerji and Nair (1970) made a quantitative assessment of the potential resources of the Indian Ocean from primary production and zooplankton biomass and examined it in the light of the results of exploratory fishing conducted at various regions. The net primary production for

an area of 51 million square kilometres of the Indian Ocean has been computed as 3.9×10^9 tonnes of carbon per year. This is in close agreement to the estimate of Koblents-Mishke et al., (1970) i.e. 4.1×10^9 tonnes.

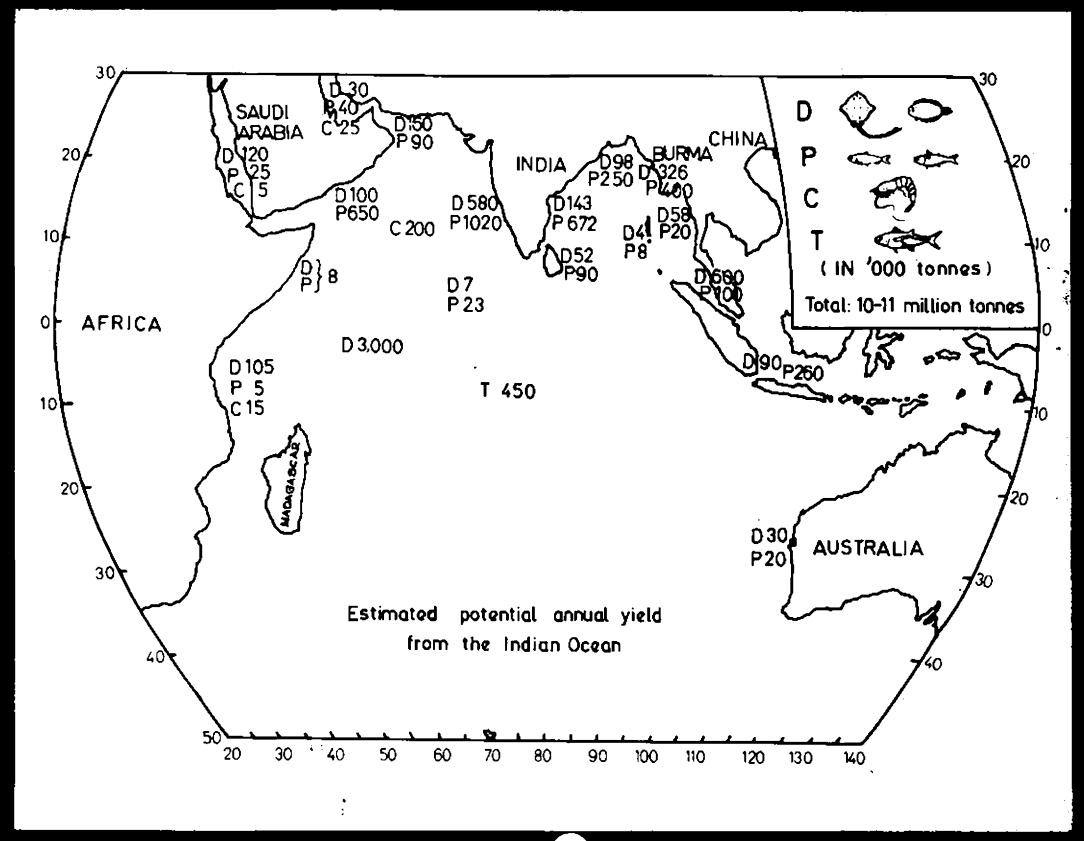
An estimate of the possible catch at the present level of world fishing is 11-12 million tonnes. This figure has been arrived at by comparison of the yield ratio in the Indian Ocean to that of the Atlantic and Pacific Oceans. But the potential harvest derived from estimates of fish biomass based on primary production and its subsequent transfer through the various trophic levels could be as high as 39-40 million tonnes. As mentioned before, in heavily exploited waters as in the North Sea and the English Channel, where optimum catch is obtained, it has been observed that carbon content of optimum fish catch divided by net production which is 60% of gross production gives a ratio of 0.004. Hence the potential yield is about 105 kg per hectare (Fig.33). Based on primary production data the probable potential increase has been worked out for the various regions (Table 25).

Fig.33. Optimum yield of fish in different regions of the Indian Ocean as estimated from primary production data.

Fig.34. A pictorial representation of the composition of the potential yield estimated from different regions of the Indian Ocean based on exploratory survey reports. D - demersal fishes, P - Pelagic fishes, C - crustaceans and T - tunas.



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Table 25. Present yield as % and the probable potential increase for the various regions of the Indian Ocean

| Region | Yield rate as % | Probable potential increase |
|-----------------------------------|--------------------|--------------------------------|
| Atlantic | 0.04 | - |
| Pacific | 0.03 | - |
| World Oceans (mean) | 0.03 | - |
| Indian Ocean (total) | 0.008 | x 5 |
| Continental shelf of Indian Ocean | 0.03 | x 10 |
| Gulf of Mannar | 0.07 | x 5 |
| West coast of India | 0.22 | x 2 |
| East coast of India | 0.14 | x 3 |

The estimates of potential yield becomes meaningful only when they are compared with the results of exploratory surveys. The potential yield of fish for the entire continental shelf area of India as estimated by Jones and Banerjee (1968) has been found to be 2,283,000 tonnes of which the share of the west coast is 1,417,000 tonnes. This estimate includes both pelagic and demersal fish. The percentage of demersal fish in the total catch varied from 28 in 1966 to 36.8 in 1969 (Table 26).

Table 26. Catch from exploited stock. Estimated region-wise distribution of pelagic and demersal fish catch based on the data collected by the Central Marine Fisheries Research Institute for 1969

| State | Pelagic | Demersal | Total |
|-------------------|-----------------|-----------------|-----------------|
| Gujarat | 63,868 | 18,380 | 82,248 |
| Maharashtra | 75,940 | 92,780 | 1,68,720 |
| Goa | 25,678 | 1,881 | 27,559 |
| Mysore | 58,904 | 16,889 | 75,793 |
| Kerala | 2,09,988 | 84,799 | 2,94,787 |
| Tamil Nadu | 73,962 | 77,914 | 1,51,876 |
| Pondicherry | 7,079 | 3,558 | 10,637 |
| Andhra | 47,680 | 29,846 | 77,526 |
| W.Bengal & Orissa | 12,967 | 9,912 | 22,879 |
| Laccadives | 884 | 309 | 1,193 |
| Andamans | 262 | 150 | 412 |
| TOTAL | 5,77,212 | 3,36,418 | 9,13,630 |

Assuming the ratio of demersal fish to be 30% on an average, the potential demersal catch for the entire Indian shelf area will be 7,00,000 tonnes and the potential pelagic yield about 1,600,000 tonnes. If intensive exploitation is possible for the entire shelf area of the Indian Ocean which comprises 307 million hectares, it would be possible to obtain an yield of 11 million tonnes from these areas. Hence theoretically a four-fold increase from the present level of exploitation should be possible even from the stocks available within the continental shelf with India's share

between 2 and 3 million tonnes or almost the present production from the entire Indian Ocean.

When these theoretical estimations are examined in the light of exploratory fishing data, available through many reports which have appeared in recent years, a more or less same picture is obtained (Anon, 1958 a, b; Losse, 1963; Masuda et al. 1964; Miette, 1967; Postel, 1965; Reed, 1964; Rhodes, 1966; Shomura et al. 1967; Tiews, 1966; Wheeler and Emmanuel, 1953; Rao, 1969; Silas, 1969).

As assessed from these exploratory surveys, the potential catch from the East African coastal fishery is 1,25,000 tonnes of fish. Demersal fishery of the offshore banks is considered to be very high amounting to 2-3 million tonnes. The potential yield from the Arabian Sea region has been estimated at 8,50,000 tonnes of demersal fish and 1,790,000 tonnes of pelagic fish with sizeable proportion of crustaceans amounting to 2,00,000 tonnes. Including the Red Sea and Persian Gulf resources the annual potential yield for the western Indian Ocean has been estimated at 6 million tonnes (Prasad, Banerji and Nair, 1970).

For the Eastern Indian Ocean the potential yield is 1,281,000 tonnes of demersal and 1,540,000 tonnes of pelagic fish. Including Indonesian waters and Australian shore the

potential yield has been estimated at 3.22 million tonnes. With the oceanic tuna resources the potential yield as deduced from the exploratory surveys is about 10-11 million tonnes of fish (Table 27; Fig. 34).

Table 27. Annual potential yield from the Indian Ocean
(in 1000 tonnes)

| Zone | Demersal (incl. crustaceans) | Pelagic | Total |
|------------------------------|---------------------------------|---------|-------------------|
| East African coast | 120 | 5 | 125 |
| East African Offshore bank | 3000 | - | 3000 |
| Somalia | - | - | 8 |
| South Arabia, Muscat, Oman | 100 | 650 | 750 |
| West Pakistan | 160 | 90 | 250 |
| India (west coast) | 580 | 1020 | 1600 |
| Maldives, Laccadives, Chagos | 7 | 23 | 30 |
| Red Sea | 125 | 25 | 150 |
| Persian Gulf | 55 | 40 | 95 |
| India (east coast) | 143 | 672 | 815 |
| East Pakistan | 98 | 250 | 348 |
| Burma | 326 | 400 | 726 |
| Thailand (west coast) | 58 | 20 | 78 |
| Malaysia (west coast) | 600 | 100 | 700 |
| Ceylon | 52 | 90 | 142 |
| Andaman and Nicobar | 4 | 38 | 12 |
| Indonesia | 90 | 260 | 350 |
| Australia | 30 | 20 | 50 |
| Oceanic Tuna | - | - | 450 |
| TOTAL | - | - | 9,679 |
| | | | <u>or</u> |
| | | | <u>10 million</u> |

The share of Indian seas towards the total production of fish from the Indian Ocean is thus 2.4 million tonnes (1.6 million tonnes from the west coast and 0.8 million tonnes from the east coast). This would mean a nearly three-fold increase from the present level of exploitation. The rather close similarity in the figure obtained from the data on primary production as well as exploratory fishing is striking and lends validity to each other.

SUMMARY

This account deals with the results of investigations on primary production and related aspects conducted in the Indian Seas since 1957 and includes the regional and seasonal variations in the rate of production, factors controlling the same and the magnitude of potential fishery resources derived from it.

Data collected for various periods using oxygen and ^{14}C techniques from the Gulf of Mannar, Palk Bay, the south-west coast of India including Laccadive Sea together with other available data form the basis of these studies.

Intensive trials on standardization and intercalibration have been carried out to make the ^{14}C data reliable and comparable. The results are presented along with the material and methods.

It is found that the shallow regions of the Gulf of Mannar and Palk Bay are very productive with an annual gross production of 443 and 561 gG/m^2 , respectively.

On the west-coast the maximum production is towards the coast within 50 m depth and gradually decreases seawards, the mean value within 50 m is $1.24 \text{ gG/m}^2/\text{day}$ with the highest rate during the south-west monsoon season.

The minimum is during the pre-monsoon when the mixed layer is deepest and moderately high rates are found during the post-monsoon. The daily rate of production for the rest of the shelf is $0.47 \text{ gC/m}^2/\text{day}$ and for oligotrophic regions outside the shelf it is only $0.18 \text{ gC/m}^2/\text{day}$.

The annual gross production for the inshore regions on the west coast within 50 m is 453 gC/m^2 and for the rest of the shelf 170 gC/m^2 . This would amount to an annual gross production of 50×10^6 tonnes of carbon for the inshore regions comprising 1,14,520 sq.km and 50×10^6 tonnes for 1,68,790 sq.km of the outer shelf regions.

The rates of primary production for the east coast are $0.63 \text{ gC/m}^2/\text{day}$ on the shelf and $0.19 \text{ gC/m}^2/\text{day}$ outside the shelf and annual estimated gross production is 25×10^6 tonnes of carbon for 1,11,150 sq.km of the shelf.

By comparison with areas where there is intensive exploitation and by tracing the carbon production through the different trophic levels using various ecological efficiency factors an estimate of a potential harvest of 3 million tonnes of fish has been derived for the Indian Seas which is about three times the present yield. The results of exploratory surveys indicate a potential yield of 2.4 million tonnes from both the coasts, lending

validity to the estimates from primary production data.

Similar calculations have been made for 51×10^6 sq. km of the Indian Ocean for which the Indian Ocean Expedition data are available. The annual net production is computed at 3.9×10^9 tonnes of carbon which is about one-fifth of the estimated world oceanic production, while the catch is only one-twentieth of the world production of marine fish. The shelf areas of the Indian Ocean alone account for 0.56×10^9 tonnes of carbon or about one-seventh of the total production in the Indian Ocean. The potential yield from the Indian Ocean at the present level of world fishing is about 11 million tonnes of fish. The Indian Seas could provide an annual sustainable yield of about one-fourth of the potential yield from the Indian Ocean as the productivity studies indicate.

In addition, the growth kinetics of the common phytoplankters in natural conditions and a green flagellate, Tetraselmis in culture have been presented.

The factors controlling production have been discussed. The availability of nutrients has been found to be the principal factor that determines the seasonal and regional variation of primary production in the Indian Seas.

The variations of the three phosphorus fractions - inorganic, organic and particulate P have been discussed in relation to the primary production in Gulf of Mannar off Mandapam. Though the rate of primary production is uniformly high, instantaneous concentration of inorganic P is low and without significant seasonal variation. But the total P, dissolved organic P and particulate P show definite seasonal variation. From primary production the rate of phosphate assimilation and regeneration have been deduced.

Total organic nitrogen values in the particulate matter converted into protein equivalents exhibit a significant correlation with primary production. However, it is found that apart from serving as a crude index of standing crop, the method does not seem to hold much promise due to the errors involved.

Four collaboration papers - one on the quantitative assessment of the potential resources of the Indian Ocean and adjoining seas, two on the primary productivity of some of the coral reefs in the Indian Seas and one on the ecology of a tidal pool are appended.

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