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STUDIES ON ORGANIC PRODUCTION—I. GULF OF MANNAR*

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INTRODUCTION

THE transformation of inorganic matter into organic matter by photosynthesis to form plant material is the most important single factor governing the productivity of any region in the sea. It is well-known that the autotrophic plants of the sea especially the plankton algae found in the upper water masses of the oceans are the prime synthesisers of organic matter which directly or indirectly serve as food for all the other organisms in the sea. But the rate and extent of this primary production is the main criterion in deciding the relative yield of various waters. Hence in fisheries research the estimation of organic production of an area gives a better understanding of the conditions affecting the production of fish.

It might be of interest to note here that the production of the entire hydrosphere has been estimated as 1.2 to 1.5 $\times$ 10^{10} tons of carbon per year (Steemann Nielsen, 1952). This is comparable to Schroeder's oft-quoted figure of terrestrial production of *ca* 2 $\times$ 10^{10} tons a year. According to Ryther (1959) the seas are more than twice as productive as the land, since Steemann Nielsen's estimates do not include the seasonal maxima. The earlier estimates of Riley (cf. Rabinowitch, 1945) are about 10 times higher than that of Steemann Nielsen.

Although considerable data are available on the standing crop of plankton, practically no information is available on the daily production of organic matter in our waters and therefore investigations were started in 1957 with a view to measuring the magnitude of production of organic matter by the plankton algae and its seasonal fluctuations.

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

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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 Verjbinskaya (1932) 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 (1935) 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 Gorgy (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 (1952 and 1958), Ryther (1956) Laevastu (1958) Steele (1961) and very comprehensively by Strickland (1960).

The first really direct method of estimating the production of organic matter using light and dark bottle method was introduced by Pütter (1924) and subsequently by Gaarder 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 and 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 and 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 and 1941b) in extensive plankton investigations of the Tortugas 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 bottle measurements are many times higher since values obtained by Ryther by such experiments are too low.

However, it has now been recognised that whatever be the cause of the discrepancies between light and dark bottle results and those obtained by C^{14} the former method is suspect and is not suited for use in oligotrophic waters. Prasad and Nair (1962) conducted a series of concurrent *in situ* experiments using 24 hour oxygen experiments and 6 hour C^{14} experiments in eutrophic and oligotrophic waters. The results obtained showed a very close similarity in eutrophic waters especially when the phytoplankton was abundant, whereas the oxygen experiments of the oligotrophic waters did not yield any convincing result.

Material and Methods

Sea water was collected from 6 stations in the Gulf of Mannar (Stations 0, I, II, III, IV and V) spread over a distance of about 30 km. (see Fig. 1) at fixed hours in bottles thoroughly cleaned with chromic acid. Without this it was found that a film of phytoplankton organisms grow rapidly on the inside which proliferate as time goes on giving abnormal values. Control bottles were painted dark. This was later substituted with amber-coloured bottles covered with a double-layered dark cloth to facilitate better cleaning as well as to prevent light penetration through small ' windows ' of broken paint. Sets of such light and dark bottles were filled with raw sea water. Care was taken that no air bubble was left in the bottle. The bottles were then suspended at the same depth by means of ' cradles ' from stands erected in the sea. When rough condition prevailed, bottles were suspended from a bamboo pole loosely tied to an anchored drum. This arrangement was found to be very convenient, since the change of levels due to tidal effect does not affect the position of bottles and also avoids the shade during the course of the experiment.

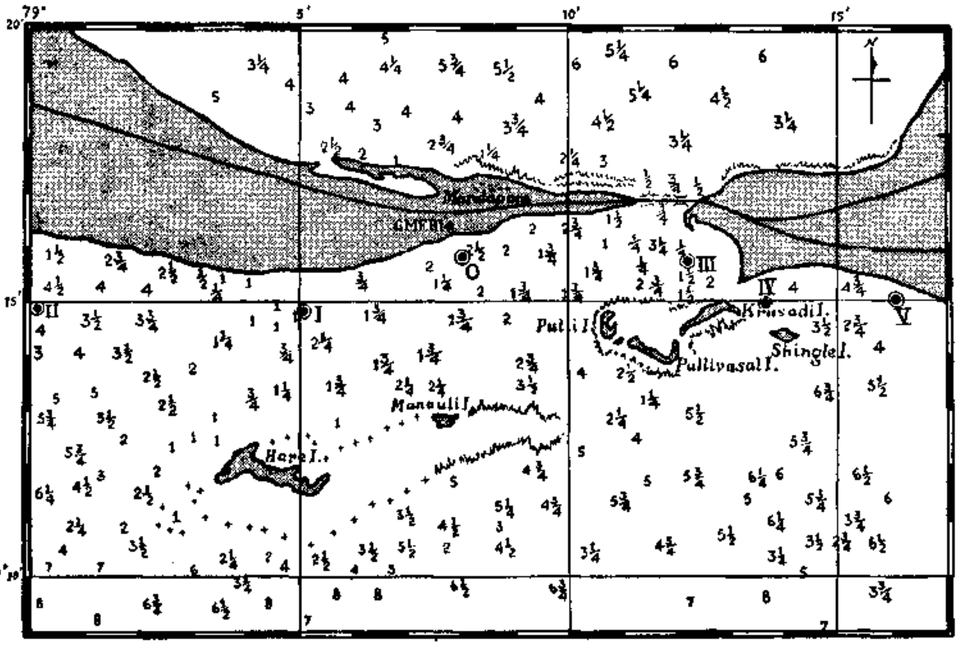

FIG. 1. Map indicating the location of Stations 0 to V. Depths indicated are in fathoms.

C^{14} experiments were conducted with standardized ampoules obtained from the International Agency for C^{14} determination, Denmark. Water samples were collected with a glass bottle having a 'snatch mechanism' and later on with an insulated water bottle with inner cylinder of plexiglass. 60 ml clear-glass bottles were filled with the sea water to which the contents of the ampoules were also added (strength 0.004 mC per ampule). These bottles were then suspended at the same depth from the float or from the side of the boat for six hours either from sunrise to noon or noon to sunset. Salinity and temperature were also recorded for the respective samples. At the end of the experimental period samples were filtered through membrane filters using a special filtering apparatus. The filters are then placed over an ordinary filter paper for the absorption of the excess sea water and prevention of the formation of salt crystals. These filters are then dried in special holders in a desiccator with calcium chloride to which a little soda lime was added and later photosynthetic rate computed.* The results discussed in this paper are based on experiments conducted regularly in the coastal waters near Mandapam since 1957.

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* The photosynthetic rates computed by the International Agency for C^{14} determination are subjected to 10% correction for metabolic discrimination of C^{14} as compared to normal C^{12} and also for the loss of part of the C^{14} assimilated due to respiration by the organisms during photosynthesis.

Identical initial samples were analysed for oxygen and plant pigments. Besides, one litre of water was sedimented with neutralised formalin, the clear portion decanted and the remaining portion centrifuged. The phytoplankton cells and animals were counted on a Sedgewick-Rafter cell. The authors are aware of the limitations of centrifugation as well as the procedures recommended for enumeration of the total population. But in the absence of the inverted microscope this procedure was adopted. According to Ballantine (1953), centrifugation of a living sample is the most satisfactory in the estimation of nannoplankton. But for the larger forms Uttermöhl's sedimentation method is supposed to give the best results.

The colorimetric determinations of pigments were made with a Hilger and Watts photoelectric absorptiometer.

It may be worthwhile here to mention about the ultimate precision of light and dark bottle method. Ryther and Vaccaro (1954) mentioned a figure of 0.1 ml $0_2/l$ as being the smallest significant difference in light and dark bottle experiments. This estimate was further reduced by Ryther (1956) to 0.05 ml $0_2/l$ if duplicate determinations were made on the samples. Strickland (1960) carrying out Winkler method under ideal experimental conditions using either a starch or a 'dead stop' electrical end point gave a standard deviation of about 0.017 ml $0_2/l$ at a level of about 6 ml $0_2/l$. According to this author, this precision cannot be improved upon by any reasonable technique and that the smallest amount of photosynthesis that can be measured by the light and dark bottle technique is some 20 mg C/m^3 with single titrations or about 15 mg C/m^3 if duplicate titrations are averaged. The present authors have conducted only single titrations.

PRIMARY PRODUCTION AND STANDING CROP OF PHYTOPLANKTON

To evaluate primary production by the plankton algae the size of gross production and net production should be known. With the light and dark bottle technique it is possible to measure gross production of the phytoplankton and also respiration of the whole community. Hence true net production is impossible to be measured with this technique. So the results discussed represent gross production in terms of carbon from oxygen production using a PQ of 1.25.*

According to McAllister *et al.* (1961) the whole question of a correct PQ value is of great importance in marine studies especially if one wishes to make an accurate estimate of carbon uptake from oxygen measurements. Most of the PQ values quoted in literature for Chlorophyceae and Bacillariophyceae are very low, being around 1.05 (see Ryther, 1956). But according to Ryther (1956) many of these results were obtained from experiments conducted at a relatively high light intensity. Steemann Nielsen (1952) and Ryther (1956) have suggested a PQ of 1.25 or even 1.33 under most marine conditions. Strickland (1960) suggests an approximate working value of 1.2 since the respiration of bacteria and zooplankton in natural populations will effectively reduce the measured PQ.

In general, the trend of seasonal progression of the standing crop of phytoplankton estimated earlier from the same locality (Prasad, 1954) and the values of

* Though the present authors favour a PQ of 1.3 (cf. Prasad & Nair, 1962) for the inshore waters of this region, a PQ of 1.25 is used for the calculations in this paper as the values of primary production were computed before the work reported in the above paper was carried out. Hence these values may be assumed to be about 4% higher.

primary production are rather similar. There are two peaks of production one in April-May and another in October. During the first year of the investigation the mean monthly values ranged from 77 mg C/m^3/day in July to 350 mg C/m^3/day in May with an average of 198 mg C/m^3/day. In the second year the values for the corresponding period were 124 mg C/m^3/day in July and 388 mg C/m^3/day in April, with an average of 202 mg C/m^3/day. This amounts to a total annual production of 72.297 g C/m^3 in the first year and 73.551 g C/m^3 in the second year for the July to June period. The average for all the six stations from 1958 to 1961 which includes more than 500 analyses using surface and bottom samples is 74.460 g C/m^3 (see Tables 3-9). Although there had been variations within and between the months and shifts in the periods of seasonal maxima the close similarity in the total annual production for two consecutive years for station 0 as well as the average for all the stations is striking and so it may be presumed to represent a reasonably true value of the magnitude of production in this area.

During April-May which is the period of phytoplankton bloom, the mean monthly production is about four times that of June-July which is a low period in phytoplankton production.

The lowest single value recorded from Station 0, where detailed weekly analyses have been conducted was in the third week of December 1957 (37 mg C/m^3/day) and the highest in the first week of May 1958 (667 mg C/m^3/day) which is about 19 times. In the last week of December 1957 an unusual bloom of coccoid Myxophyceae brought about a sudden rise in production (647 mg C/m^3/day). Occasionally, certain very high values have been obtained due to abnormal decrease of oxygen in the dark bottles. Such values have been discarded as faulty experiments.

It may be interesting to compare the oxygen production values with those obtained elsewhere using similar technique. For the sake of comparison the values of oxygen have been converted into milligrammes per litre. The mean oxygen production of the 43 analyses with complete sets of data extending over a period of 12 months from July 1957 to June 1958 is 0.688 mg/1/day, the range of the individual experiments being 0.121 mg/1 to 2.214 mg/1/day. Gran (1927) estimated that the mean production in the coastal waters off Bergen was 0.370 mg/1/day during the spring bloom of 1922. Marshall and Orr (1930) obtained a value of 0.430 mg/1/day in Loch Striven in April, 1926. The mean quantity of oxygen produced in all samples of surface water measured by the Winkler method was 0.187 mg/1/day and for station 2 it was 0.131 mg/1/day (Riley, 1938). In the western north Atlantic during May-June Riley (1939) found a mean oxygen production of 0.111 mg/1/day ; for the northern waters the mean was 0.180 mg and in the southern waters it was 0.091 mg. According to the same author (1941a) oxygen production at the surface in Long Island Sound varied from 0.05 to 1.08 mg/1/day with an average of 0.466 mg representing the fixation of 175 mg C/m^3/day. During six cruises in Georges Bank, Riley (1941b) noted an average oxygen production ranging from 0.036 mg/1/day in January to 1.450 mg/1/in April the latter value for the shallow water. The highest single value in April for the same area was 2.35 mg/1 which is equivalent to 707 mg C/m^3/day. Thus it may be seen that the rate of production in the inshore waters of the Gulf of Mannar is high but not unusual (see Table 10). C^{14} experiments conducted subsequently at different times of the year also confirm this fact. It may be pointed out here that Steemann Nielsen and Jensen (1957) found during the *Galathea* Expedition that the rate of organic production practically anywhere in the tropics in shallow waters is high. In Walvis Bay, the most productive region observed by them in the world, the rate of production at the surface was 6600 mg C/m^3/day. If it is assumed that the measurement at Walvis Bay was made during one of the peak periods it may be said that when calculated per unit volume, the production rate in the Gulf of Mannar is about one-tenth of Walvis Bay. When calculated per unit area it will be only little less than half. The difference may be accounted by the difference in the depths of the photosynthetic zones.

C^{14} experiments conducted at random concurrently with the oxygen experiments yielded very interesting results (*cf.* Prasad and Nair, 1962). In all the experiments conducted in the nearshore shallow waters the rate of production was high at the surface. But in deeper waters (off Pooma channel) near the present 6 stations as well as those conducted at Tuticorin the rate of production was highest at 10 metres. In the waters off Tuticorin where the photosynthetic zone extends over 40 metres, the rate of production at 10 metres was 252.6 mg C/m^3/day on 10-8-1961. When calculated per unit area, production would amount to over 5 g C/m^3/day. This high rate, especially at a time when there was no bloom of phytoplankton, indicates that the waters off Tuticorin must be remarkably productive. The trawling grounds of Pinnakkayal also was found to be very productive and showed a rate of 202.5 mg C/m^3/day at the surface during the same period.

Another interesting observation made was that when the same station was sampled in the forenoon it showed a fourfold rate of production compared to that of afternoon. Experiments were conducted from 6 a.m. to 12 noon and from 12 noon to 6 p.m. when a suppression of photosynthesis was noticed in the afternoon. The bottom values were nearly the same. The dark fixation of tracer carbon was less than 1% at the surface whereas it was over 2% at the bottom. In this connection it may be pointed out that according to Steemann Nielsen (1960) dark fixation in water from the photic layer is mostly about 1-2% of the fixation at optimal light intensity but may also be as high as 5%. Grøntved (1962) observed high percentage figures for dark fixation in the suspensible bottom material which he believes to be due to a great population of heterotrophic micro-organisms in the upper bottom layers. Hence it is likely that in the present instance also the higher percentage observed in the bottom samples is due to the presence of more suspended matter containing a greater number of heterotrophic micro-organisms. The results of the observations are given in Table 11.

The standing crop of phytoplankton in terms of plant pigment units (Harvey units) ranged from 9,000 H.U./m^3 in October to 58,000 H.U./m^3 in April (mean monthly values). The range of individual estimates was 6,000 H.U./m^3 in the third week of October to 96,000/m^3 in the third week of April with an average of 27,000 H.U./m^3 for the year. Off Waltair on the east coast (Ganapati and Subba Rao, 1958) pigment values have been found to range from 8,246 H.U./m^3 in April to 67 H.U./m^3 in December (mean monthly values). Individual values ranged from 18,550 H.U. and 28 H.U. in March and December respectively. Higher values associated with abundance of dinoflagellates were also observed by these authors with ethyl alcohol-benzene as the solvent. The average for the year was 2,027 H.U. Off Calicut on the west coast which is a highly productive area the pigment values ranged from 4,000 H.U./m^3 to 2,48,000 H.U./m^3 the high values associated with the south-west monsoon period (Subrahmanyan, 1959). Mean monthly values were found to vary from 12,714 H.U./m^3 in November to 92,800 H.U./m^3 in July. The average for the year 1955-56 was 38,000 H.U. and for the five-year period over which the studies were conducted it was 22,000 H.U. It may be seen from these values that the standing crop of phytoplankton in the Gulf of Mannar, as estimated by pigment method, is also quite high. The average value compares favourably with that of the west coast, though the peak value off Calicut is 2½ times higher, and is 13 times higher than that of Waltair coast. The exact quantitative comparisons of the standing crop based on pigment values may be untenable. However, evidence of this significant difference in the magnitude is reflected in the number of phytoplankton cells as well.

Monthly average of phytoplankton cells, obtained by sedimentation and centrifugation varied from 360 cells/1 in August to 5,83,000 cells/1 in April. In the individual samples the variation was from 100 cells/1 in the first week of August to 11,42,000 cells/1 in the last week of April. The number of cells at the beginning of the experiment, the final values in the light bottles and the net increase due to growth during the experiment were found to follow the same pattern of relationship with oxygen production (Fig. 2).

STANDING CROP OF ZOOPLANKTON

The zooplankton counts were made from the same centrifuged samples from which the phytoplankton counts were also made. Analysis of the percentage composition of the zooplankton showed that copepods, nauplii and tintinnids commonly formed the bulk of the standing crop with a mean of 23.4%, 24.8% and 28.0% respectively. On a few occasions *Noctiluca* or lamellibranch larvae have also dominated. Gastropod larvae, polychaetes, etc., were found to occur commonly but not in large numbers. The relationship of the animal population with oxygen production as well as with phytoplankton were found to be generally negative. It must, however, be mentioned that estimation of the number and kind of animals from one or two litres of water as was done in the present instance is not adequate for sampling the population as a whole except within fairly wide limits of error. One assumption that is made with regard to the estimation of zooplankton is that the initial sample that is analysed and the samples in the light and dark bottles contain the same numbers of animals within errors of sampling. In the Long Island Sound waters Riley (1941a) observed a decrease in the mean quantity of animals at the end of the experiment in the light and dark bottles, and he concluded that the zooplankton does not thrive in the experimental bottles and that light is not connected with the decrease as the average was almost the same in both the bottles. In 43 experiments of 48 hours duration conducted by the present authors the mean quantity of animals in the initial samples was 77.6/1. At the end of the experiment it was 66.3/1 in the light bottles and 45.0/1 in the dark bottles. Apparently this is in agreement with Riley's observation. But an examination of the data of individual experiments revealed that there were only 11 instances of such decrease in the light bottles and 20 instances in the dark bottles. Hence it is to be inferred that this phenomenon is more the result of vagaries of sampling than due to the conditions in the experiment.

DISCUSSION

In an evaluation of relationships of the different biological factors with oxygen production it may be seen that the phytoplankton cell numbers do not always correspond with pigment values. In April an average phytoplankton count of about 5,83,000 cells/1 coincided with an average pigment value of 58,000 H.U./m^3.

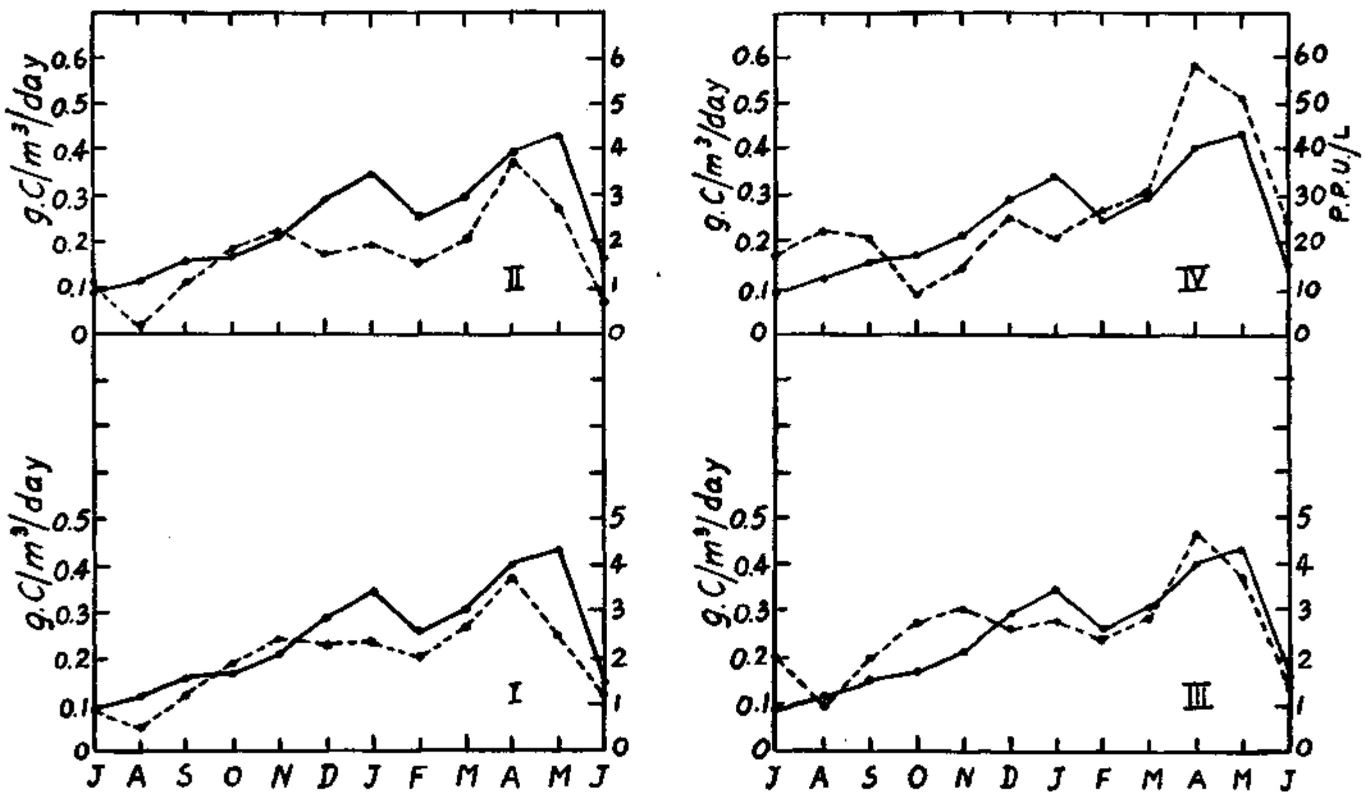

FIG. 2. I. Organic production and log. of initial phytoplankton cells/l (in 100). II. Organic production and log. of phytoplankton cells in L.B. at the end of experiments (in 1000). III. Organic production and log. of increase of phytoplankton cells in the L.B. (in 100). IV. Organic production and plant pigment units/l. In I to IV the continuous line represents organic production and the broken line in I to III represents log. of phytoplankton cells.

Both values are highest for the year. The lowest mean monthly value of pigments, 9,000 H.U./m^3 in October corresponded with an average phytoplankton count of about 8,600 cells/1. But in June and July more than two-fold increase in pigment values was found to correspond with only one-tenth of the number of cells and much less in August. Considering the importance of nannoplankton in primary production as revealed by Rodhe *et al.* (1958) who have shown by ' fractional filtration' that there is a 90% contribution (even higher during spring blooms) by nannoplankton, it may be interpreted that the disagreement might be due to the inadequacy of the counting technique. But the oxygen production value which is an index of photosynthesis and thereby indicative of living chlorophyll, was distinctly lower during the period. Hence it points to the fact that the incongruity may not be due to nannoplankton alone which has not been accounted for while counting.

Analysis of the data for a whole year showed a significant positive correlation between phytoplankton cells and pigment units. Though this is to be expected, a negative correlation between pigment values and cell numbers during the months, when turbulent conditions prevail in the Gulf, coupled with low oxygen production suggest the influence of organic detritus, which has no bearing on photosynthesis. Strickland's (1960) remarks on the validity of giving too much emphasis on pigment values as indices of standing crop may be recalled in this context. 'Although it originally had something to recommend it for field work, where the absence of a colorimeter or stable chlorophyll standards might otherwise have prevented any measurements being undertaken, nevertheless the procedure introduces yet another uncertainty in the chain of calculations leading to final standing crop values (Section II,B). In retrospect it is to be regretted that so many field observations are now available only in the form of Harvey Plant Pigment Units.'

It was found that at the end of 48 hours of the experimental period there was a distinct increase in cell numbers in the light bottles which represents the net increase of phytoplankton due to reproduction during the experiment. Increase in pigment values, however, was erratic. The net increase of cells based on monthly averages varied from 3-10 times the initial numbers. Net increase in individual experiments reached up to even 20 times in the month of May when the highest value of oxygen production was obtained. This differential rate of growth seems to be the result of variations in the nature of the individual species that make up the community. The diatom flora mainly consisted of typical littoral forms like *Navicula*, *Pleurosigma*, *Nitzschia*, etc. Pelagic forms like *Chaetoceros* spp., *Bacteriastrum* spp., *Thalassionema nitzschioides*, *Thalassiothrix frauenfeldii* and *Asterionella japonica* also were common and sometimes abundant. Of these *Chaetoceros* spp. showed a daily increase of 950% in April (19 times in 48 hours) and 3283% in October (65 times in 48 hours), whereas littoral diatoms like *Navicula*, exhibited much less rate of growth. The mean growth rate from all the experiments was 319%. Pratt and Berkson (1959) found that diatoms showed a mean increase of 264% in 22 experiments that have been averaged, all the diatom species represented taking part in the increase. Smayda (1957) gave an average increase in the light bottle of only 53%.

Pratt and Berkson (*l.c.*) have observed that the development of phytoplankton bloom increases the surface available to bacteria and the activity of the bacteria in turn increases the rate of supply of nutrients to the photosynthetic plankton, which is thereby stimulated to multiply further, thus providing additional bacterial substrate. These authors also found that a wisp of glass wool added to the light bottle enhances diatom increase consistently. In the light of this observation it may be interpreted that the very high rate of growth observed in setaceous forms like *Chaetoceros* may be the result of a large number of bacteria being harboured due to the greater surface area rendered by the setae and thereby bringing about the autoacceleration process described above.

Harvey *et al.* (1935) have shown that the size of the standing crop of phytoplankton is largely controlled by animal consumption. It was found that the spring outburst of diatoms was limited in quantity and time by the grazing of herbivorous plankton animals which appear to eat greatly in excess of their needs, when diatoms are abundant. So it can be seen that the standing crop of phytoplankton because of the opposite effects of growth and grazing is more a dynamic entity than a static one and according to Riley (1939) it is useless to gauge production by the size of the standing crop.

Considering the various aspects of the problem an attempt has been made to evaluate the relations between the oxygen production and important biological factors like plant pigments or cells and the animals. In the 50 experiments of 48 hours duration conducted during the first year, 43 have been taken for statistical analysis. The rest were not included either due to incompleteness of the data or due to faulty experiments. The coefficients of correlation have been tabulated in Table 1.

TABLE 1

	No. of cells	O_2 production	No. of animals
Plant pigments	+0.542	+0.314	−0.111
No. of cells	—	+0.365	−0.060
O_2 production	—	—	−0.132

Test of significance for the correlation coefficient was carried out and it was found that the relation between pigment and cells and that with oxygen production are significant. The chief factors affecting oxygen production are the standing crop of phytoplankton expressed as units of plant pigments or numbers of cells (expressed in thousands) and animals, the relation of the latter was found to be not significant. Theoretically the relation between the number of cells and pigments should be positive. When the 43 experiments spread throughout the year are taken into consideration the correlation is +0.542 which is highly significant. But for July to October it is −0.413. This negative relation is presumably caused by the turbulent condition in the Gulf. So if the data had been confined to shorter periods especially to the months with turbulent conditions the relation between these two factors would have been distorted. It is presumed that the negative relation of this period has been greatly offset by the strong positive relation during the rest of the period which has given a reasonable picture of the relationship of these two units. So it is felt that pigment estimates to assess standing crop or as indices of production should be used with caution taking into full consideration the physical features of the area of investigation and the geographical conditions during the experimental period. In the absence of better facilities for gauging production, the standing crop in terms of numbers of plant cells, taking all size groups into account, can be used more safely as indices of production than pigment estimates.

Organic Production in Relation to the Local Fishery

The authors earlier estimated the annual production in the same area while making a preliminary assessment of the fisheries potential of this zone (Prasad and Nair, 1960). Though the basic calculations involved are the same, the application of a different PQ has necessitated a recalculation of the magnitude of production. According to this revised estimate the annual organic production would amount to *ca* 4,296,000 tonnes for an area of 3,900 square kilometres of the sea with an average depth of 15 metres extending from Dhanushkodi to Cape Comorin. In view of the high rate of production per square metre of the sea surface observed in the deeper waters it may be mentioned that this is only a modest estimate which covers only a narrow inshore belt 16 kilometres wide normally frequented by the fishermen with country crafts. According to the data provided by the Fishery Survey Division of the Central Marine Fisheries Research Institute, the fish landings for the period 1957 July to December 1961 have been plotted against the mean monthly values of organic production (Fig. 3). It is interesting to note that the seasonal rhythm in organic production is reflected well in the trend of fishery. The peak periods of production correspond with the low periods in fishery and *vice versa* suggesting an inverse relation. But since a high fishery follows after a peak production of organic matter in regular sequence with a more or less uniform time lag, the trend of fishery will be the reflection of the trend of organic production and the time lag in the peaks is the time taken for the conversion of the organic matter synthesised to form fish protein.

The annual organic production has been computed from all the analyses conducted during the respective years. Assuming that 50% of the fish protein is carbon (i.e., 10% of wet weight) the percentage yield in terms of carbon for the four years, 1958 to 1961 is given in Table 2.

Table 2

Total organic production and total fish landings

Year	No. of experiments (Total No. of Stations in brackets)	Total organic production (Tonnes)	Fish landing (Tonnes)	Percentage yield of organic production
1958	43(1)	4,654,845.0	19,553.28	0.042
1959	198(6)	4,146,655.5	14,048.42	0.034
1960	213(6)	3,888,319.5	12,053.95	0.031
1961	62(5)	5,139,517.5	11,153.75	0.022

It will be seen from Table 2 that the magnitude of organic production shows a decrease from 1958 to 1960 and then an increase. This increase in production noticed in 1961 does not appear to be real because the sampling during the parti-

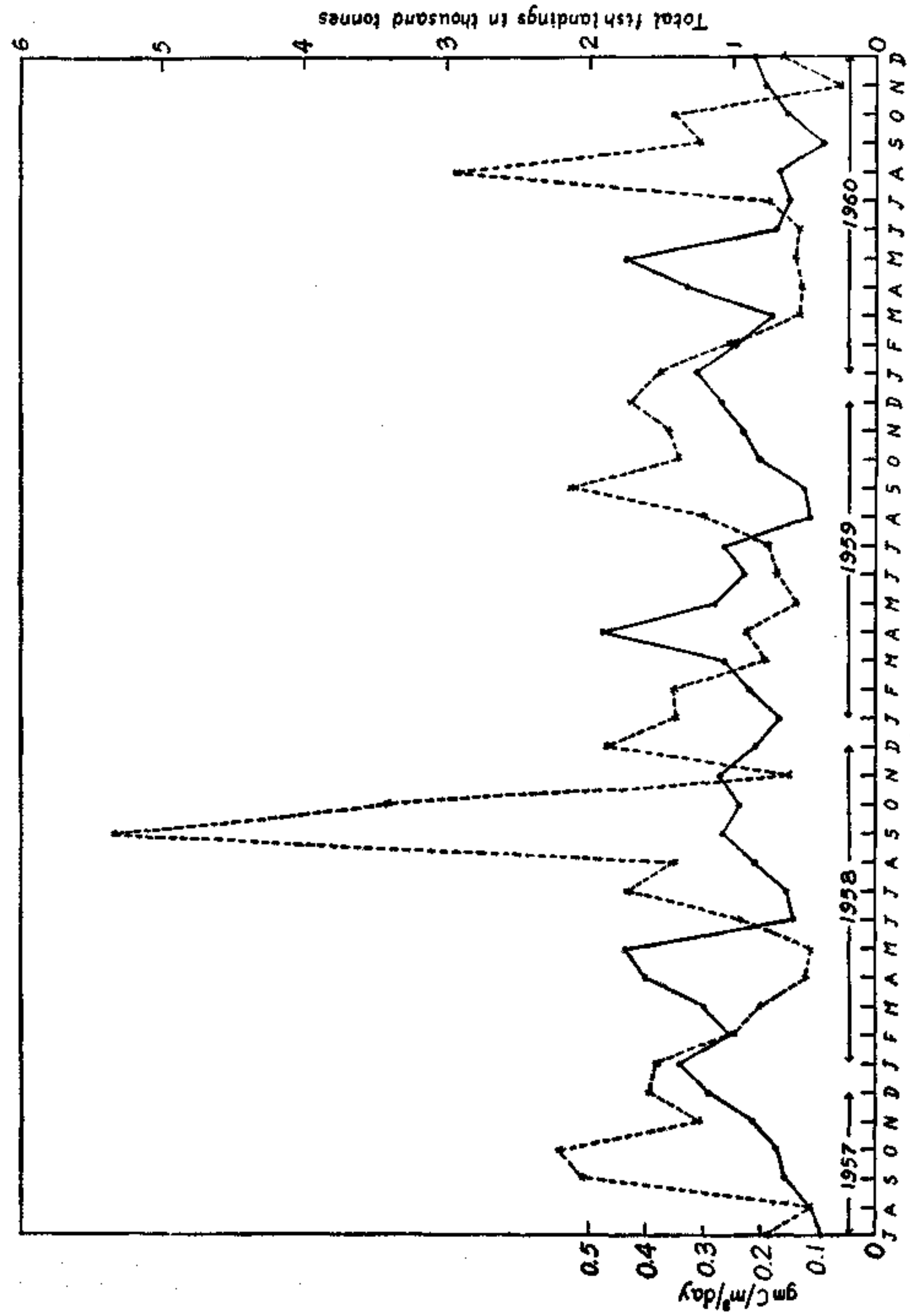

FIG. 3. Organic production (continuous line) and total fish landings (broken line).

cular year, owing to operational reasons, could not be adequate and as such does not give complete coverage of the low and high periods of production. It is likely that more intensive sampling, as carried out in the previous years, would have revealed the downward trend in the total organic production which is also well reflected in the total fish landings. However, in the case of fish landing data too (Table 2) it should be mentioned that due to a re-orientation of the fishery survey zones the total fish landings for 1960 and 1961 may not include a small portion of the landings from the Gulf of Mannar area of the Pamban Island. The downward trend noticed is, in all probability, not anything abnormal, but only the usual cyclic changes that could be expected.

As stated by the authors in their earlier report (1960) compared to intensely exploited waters where 0.2% to 0.3% of the carbon fixed is taken as fish, the present yield from this zone is only about one-seventh to one-tenth of a possible exploitable stock. The possibility of increasing the rate of exploitation has been very well substantiated by the encouraging results of exploratory fishing conducted recently by R. V. *VARUNA* in the area of investigations. Trawling operations were carried out off Mandapam with an Otter Trawl without rollers and having a foot rope of 50 metres and opening of 20 metres at a speed of 2 knots between 10 and 25 metres depth on four days from 30-1-63 to 5-2-63. The total catch from 8 hauls lasting about an hour each was nearly 8 tonnes. On 5-2-63 during two hauls, each lasting one and a quarter hours made at 9°5′ 30″N. and 79°11′ 24″ E. alone produced a total catch of 3.5 tonnes (Pl. I, Figs. 1-3) comprising mostly *Leiognathus*, *Polynemus*, *Sciaena*, *Sardinella* spp., rays, sharks, catfishes, *Cybium*, *Pomadasys*, *Stromateus*, *Lactarius*, etc., in the order of abundance. Hence it seems certain that large stocks of fish are available in this area and the present yield could be easily stepped up with a little more effort.

SUMMARY

Study of organic production was initiated in the inshore waters of the Gulf of Mannar to determine the magnitude of production, its seasonal variations and the present yield in terms of carbon with a view to assess the fisheries potential.

Organic production values determined with oxygen technique as well as C^{14} technique have been compared with values obtained elsewhere. Standing crop of phytoplankton determined as Harvey Pigment Units or total number of cells also have been compared with other observations made in Indian waters.

Initial values of plant pigments and phytoplankton cells and increase of cells in the light bottle were found to follow more or less the same pattern as organic production.

Analysis of the data indicated that values of plant pigment units can sometimes give erratic pictures of standing crop especially during turbulent conditions.

It is found that the standing crop as well as organic production is high in the inshore waters of the Gulf of Mannar.

The trend and magnitude of production are reflected in the fishery. It is also found that the present yield could be easily stepped up with a little more effort.

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* Not referred in the original.

APPENDIX

TABLE 3

Gulf of Mannar : Station O—Surface

Date	Initial O_2 cc/1	O_2 prod. cc/1/day	O_2 consump. cc/1/day	Gross prod. mg.C/m³/day	Temp. °C	S‰	Plant pigment units/1	Phytoplankton cells/1	Animals /1	Increase of phytoplankton cells/1 in the L.B.
16-7-1957	3.14	0.150	0.135	64.5	28.6	35.5	9	640	9	1,410
23-7-1957	4.93	0.180	0.120	77.4	30.5	35.4	18	280	26	1,824
30-7-1957	4.23	0.210	0.090	90.3	28.5	33.9	25	1,870	63	29,730
6-8-1957	3.81	0.150	0.060	64.5	29.6	34.7	11	100	134	1,230
12-8-1957	3.71	0.300	0.220	129.0	29.7	34.1	28	670	11	850
19-8-1957	3.99	0.150	0.000	64.5	28.5	35.6	28	150	24	410
27-8-1957	3.99	0.290	0.105	124.7	29.3	35.7	20	510	7	1,280
2-9-1957	3.93	0.240	0.210	103.2	29.2	36.8	44	350	13	340
10-9-1957	4.53	0.270	0.150	116.1	29.5	35.6	16	1,520	68	20,800
17-9-1957	4.41	0.270	0.630	116.1	30.0	35.7	17	1,280	51	13,210
24-9-1957	4.20	0.405	0.195	174.2	30.0	35.4	7	4,190	62	8,120
9-10-1957	4.23	0.240	0.210	103.2	28.5	35.4	13	150	9	1,690
15-10-1957	4.35	0.570	0.330	245.1	30.5	35.6	7	6,600	67	3,17,350
22-10-1957	4.17	0.210	0.210	90.3	29.6	33.9	6	300	48	10
29-10-1957	3.92	0.250	0.055	107.5	29.5	34.1	10	3,380	10	1,680
5-11-1957	3.36	0.250	0.110	107.5	29.0	32.5	15	350	1,498	3,040
12-11-1957	4.10	0.365	0.145	157.0	29.3	31.6	12	34,540	63	2,19,060
19-11-1957	4.09	0.615	0.030	264.5	27.2	27.8	11	12,730	121	1,38,930
26-11-1957	4.48	0.365	0.280	157.0	26.9	26.6	17	61,480	111	1,75,880
3-12-1957	3.14	0.535	0.045	230.1	26.9	27.6	14	22,940	94	1,00,790
10-12-1957	4.20	0.585	0.265	251.6	26.5	27.5	9	16,980	43	81,230
17-12-1957	3.95	0.115	—	49.4	27.0	28.9	—	24,030	90	27,950*
24-12-1957	3.58	0.085	—	36.6	25.8	31.1	57	20,630	117	27,550
31-12-1957	3.92	1.420	0.140	647.2	25.9	28.2	23	8,770	13	76,630
7-1-1958	3.81	1.140	0.045	490.2	26.1	27.1	22	24,870	39	83,000
15-1-1958	4.26	0.530	0.060	227.9	26.9	26.8	19	14,610	28	40,270
21-1-1958	4.60	0.465	0.090	200.0	26.5	26.2	21	33,420	16	51,690
28-1-1958	4.03	0.475	0.195	204.2	27.4	27.1	—	51,180	177	68,010
4-2-1958	4.42	0.560	0.280	240.8	26.6	26.4	13	7,610	48	15,870
11-2-1958	4.26	0.460	0.100	197.8	28.6	30.2	43	8,320	44	3,890
18-2-1958	3.56	0.385	0.135	165.6	27.0	28.2	24	15,210	36	76,790
25-2-1958	3.32	0.490	0.060	210.7	29.2	30.9	—	15,360	24	17,100*
4-3-1958	3.48	0.335	0.095	144.1	29.1	31.4	—	19,870	45	27,840*
11-3-1958	3.37	0.650	0.325	279.5	29.2	31.8	24	6,200	39	44,970
18-3-1958	3.96	0.520	0.355	223.6	29.7	32.0	38	21,090	30	2,00,110
25-3-1958	4.18	0.760	0.540	326.8	31.1	31.3	28	1,15,090	14	48,420
1-4-1958	3.42	0.540	0.215	232.2	30.6	32.7	64	27,710	21	29,890
8-4-1958	3.53	0.760	0.300	326.8	32.0	33.1	—	15,10,000	20	35,10,000*
15-4-1958	3.37	0.635	0.190	273.1	31.5	32.9	21	1,59,000	22	3,17,000
22-4-1958	3.53	1.105	0.515	475.2	31.5	33.6	96	11,42,000	18	2,08,82,000
29-4-1958	3.58	0.735	0.270	316.1	31.7	33.2	52	76,200	19	6,67,800
6-5-1958	3.48	1.550	0.655	666.5	30.3	32.7	32	62,800	42	19,69,200
13-5-1958	3.45	0.460	0.175	197.8	30.4	33.6	61	22,200	37	26,600
20-5-1958	3.80	0.815	0.395	350.4	31.8	34.1	90	30,400	53	1,85,600
27-5-1958	3.69	0.435	0.190	187.1	30.4	33.4	19	10,400	56	8,600
4-6-1958	4.02	0.280	0.220	120.4	30.4	34.5	25	2,200	64	5,600
10-6-1958	4.02	0.245	0.220	105.4	29.7	34.9	—	—	—	—*
17-6-1958	4.56	0.190	0.160	81.7	29.3	35.4	15	3,000	21	600
24-6-1958	4.10	0.380	0.285	163.4	—	35.1	32	410	27	360

*Not taken for analysis. L. B. Light bottle.

TABLE 4

Gulf of Mannar : Station 1

Date	Surface		Bottom	
	Oxygen prod. cc/l	Carbon mg/m³/day	Oxygen prod. cc/l	Carbon mg/m³/day
23-1-1959	0.220	94.6	0.590	253.7
6-2-1959	0.560	240.8	0.390	167.7
27-2-1959	0.170	73.1	0.080	34.4
20-3-1959	0.200	86.0	0.050	21.5
8-5-1959	0.170	73.1	—	—
15-5-1959	0.420	180.6	0.200	86.0
12-6-1959	0.450	193.5	0.140	60.2
10-7-1959	0.190	81.7	0.250	107.5
31-7-1959	0.250	107.5	0.130	55.9
28-8-1959	1.660	713.8	0.060	25.8
11-9-1959	—	—	0.440	189.2
16-10-1959	0.060	25.8	—	—
6-11-1959	0.670	288.1	0.340	146.2
20-11-1959	0.530	227.9	0.160	68.8
11-12-1959	0.280	120.4	0.250	107.5
1-1-1960	0.480	206.4	—	—
15-1-1960	0.310	133.3	0.310	133.3
5-2-1960	0.420	180.6	0.060	25.8
19-2-1960	0.590	253.7	0.260	111.8
11-3-1960	0.440	189.2	0.140	60.2
1-4-1960	—	—	0.260	111.8
22-4-1960	0.400	172.0	—	—
6-5-1960	0.622	267.5	0.409	175.9
17-6-1960	0.750	322.5	0.359	154.4
1-7-1960	0.060	25.8	0.049	21.1
22-7-1960	0.291	125.1	—	—
19-8-1960	0.159	68.4	0.181	77.8
16-9-1960	0.352	151.4	—	—
30-9-1960	0.834	358.6	0.083	35.7
4-11-1960	0.838	360.3	0.310	133.3
2-12-1960	0.348	149.6	0.104	44.7
23-12-1960	0.011	4.7	0.126	54.2
20-1-1961	0.114	49.0	1.023	439.9
17-2-1961	0.478	205.5	0.353	151.8
21-4-1961	0.341	146.6	0.509	218.9
5-5-1961	0.689	296.3	—	—
16-6-1961	0.772	332.0	0.269	142.6
14-7-1961	0.446	191.8	0.997	428.7
1-12-1961	0.134	57.6	0.627	269.6
22-12-1961	0.340	146.2	0.140	60.2
5-1-1962	0.390	167.7	—	—

TABLE 5

Gulf of Mannar : Station II

Date	Surface		Bottom	
	Oxygen prod. cc/l	Carbon $mg/m^3/day$	Oxygen prod. cc/l	Carbon $mg/m^3/day$
6-2-1959	0.280	120.4	0.280	120.4
27-2-1959	0.100	43.0	—	—
20-3-1959	—	—	0.050	21.5
15-5-1959	0.670	288.1	1.120	481.6
12-6-1959	0.090	38.7	0.390	167.7
31-7-1959	0.060	25.8	0.160	68.8
11-9-1959	0.330	141.9	0.080	34.4
16-10-1959	0.300	129.0	—	—
20-11-1959	0.470	202.1	0.310	133.3
11-12-1959	0.250	107.5	0.310	133.3
1-1-1960	0.280	120.4	0.080	34.4
15-1-1960	0.510	219.3	0.030	12.9
5-2-1960	0.320	137.6	—	—
11-3-1960	0.370	159.1	0.420	180.6
22-4-1960	0.740	318.2	0.430	184.9
6-5-1960	0.665	286.0	0.910	391.3
17-6-1960	0.169	72.7	—	—
22-7-1960	0.770	331.1	—	—
19-8-1960	0.538	231.3	0.302	129.9
16-9-1960	0.401	172.4	0.098	42.1
30-9-1960	0.055	23.7	0.213	91.6
4-11-1960	0.261	112.2	0.244	104.9
2-12-1960	0.816	350.9	0.343	147.5
23-12-1960	0.033	14.2	0.016	6.9
20-1-1961	0.933	401.2	0.348	149.6
17-2-1961	0.364	156.5	0.288	123.8
21-4-1961	0.319	137.2	0.236	101.5
5-5-1961	1.700	731.0	—	—
16-6-1961	0.532	282.0	0.799	343.6
14-7-1961	1.311	563.7	0.801	344·4
1-12-1961	—	—	1.064	457.5
22-12-1961	0.940	404.2	0.680	360.4
16-2-1962	1.190	511.7	0.130	55.9

TABLE 6

Gulf of Mannar : Station III

Date	Surface		Bottom	
	Oxygen prod. cc/l	Carbon mg/m³/day	Oxygen prod. cc/l	Carbon mg/m³/day
31-1-1959	0.970	417.1	0.700	301.0
20-2-1959	0.030	12.9	0.130	55.9
13-3-1959	0.650	279.5	—	—
3-4-1959	0.880	378.4	0.720	309.6
1-5-1959	1.030	442.9	0.470	202.1
5-6-1959	0.670	288.1	0.900	387.0
19-6-1959	0.400	172.0	0.750	322.5
3-7-1959	1.020	438.6	—	—
24-7-1959	0.800	344.0	0.280	120.4
21-8-1959	0.160	68.8	0.080	34.4
4-9-1959	0.410	176.3	0.160	68.8
18-9-1959	0.550	236.5	—	—
13-11-1959	—	—	0.310	133.3
4-12-1959	0.860	369.8	0.480	206.4
18-12-1959	0.650	279.5	0.530	227.9
8-1-1960	0.360	154.8	0.560	240.8
22-1-1960	0.730	313.9	0.300	129.0
11-2-1960	0.340	146.2	0.250	107.5
4-3-1960	0.420	180.6	0.180	77.4
18-3-1960	0.470	202.1	0.140	60.2
8-4-1960	0.230	98.9	—	—
13-5-1960	0.646	277.8	1.275	548.2
24-6-1960	0.550	236.5	0.702	301.9
15-7-1960	0.230	98.9	0.730	313.9
29-7-1960	0.098	42.1	0.264	113.5
2-9-1960	0.478	205.5	0.319	137.2
23-9-1960	0.269	115.7	0.335	144.1
28-10-1960	0.870	374.1	0.528	227.0
25-11-1960	0.212	91.2	0.289	124.3
16-12-1960	0.805	346.2	0.049	21.1
30-12-1960	0.125	53.8	0.397	170.7
6-1-1961	0.034	18.0	0.294	126.4
27-1-1961	0.408	175.4	1.018	437.7
24-2-1961	0.283	121.7	0.125	53.8
28-4-1961	0.426	183.2	0.157	67.5
2-6-1961	0.750	322.5	0.672	289.0
29-12-1961	0.100	43.0	0.450	193.5
19-1-1962	—	—	0.170	73.1

TABLE 7

Gulf of Mannar : Station IV

Date	Surface		Bottom	
	Oxygen prod. cc/l	Carbon mg/m³/day	Oxygen prod. cc/l	Carbon mg/m³/day
20-2-1959	0.090	38.7	0.050	21.5
13-3-1959	0.650	279.5	—	—
3-4-1959	0.450	193.5	0.220	94.6
1-5-1959	—	—	0.750	322.5
5-6-1959	1.420	610.6	—	—
19-6-1959	0.730	313.9	0.580	249.4
3-7-1959	0.960	412.8	—	—
24-7-1959	0.830	356.9	0.110	47.3
21-8-1959	—	180.6	0.270	116.1
4-9-1959	0.420	180.6	—	—
23-10-1959	0.410	176.3	—	—
13-11-1959	0.860	369.8	—	—
4-12-1959	0.700	301.0	0.960	412.8
18-12-1959	0.340	146.2	0.300	129.0
8-1-1960	0.420	180.6	0.390	167.7
22-1-1960	0.620	266.6	0.640	275.2
11-2-1960	0.310	133.3	0.360	154.8
4-3-1960	0.450	193.5	0.280	120.4
18-3-1960	0.340	146.2	1.010	434.3
8-4-1960	1.090	468.7	0.150	64.5
13-5-1960	1.275	548.2	0.679	292.0
24-6-1960	0.065	28.0	—	—
15-7-1960	0.258	110.9	0.373	160.4
29-7-1960	0.170	73.1	0.807	347.0
2-9-1960	0.050	21.5	—	—
23-9-1960	0.065	28.0	0.279	120.0
28-10-1960	0.572	246.0	0.756	325.1
25-11-1960	0.370	159.1	0.299	128.6
16-12-1960	—	—	0.516	221.9
30-12-1960	0.136	58.5	0.120	51.6
6-1-1961	0.435	187.1	0.299	128.6
27-1-1961	0.685	294.6	1.072	461.0
24-2-1961	0.348	149.6	—	—
28-4-1961	0.417	179.3	—	—
2-6-1961	1.237	531.9	1.053	452.8
29-12-1961	0.240	103.2	—	—
19-1-1962	—	—	0.640	275.2

TABLE 8

Gulf of Mannar : Station V

Date	Surface		Bottom	
	Oxygen prod. cc/l	Carbon mg/m³/day	Oxygen prod. cc/l	Carbon mg/m³/day
20-2-1959	0.170	73.1	—	—
13-3-1959	0.220	94.6	—	—
3-4-1959	0.860	369.8	1.360	584.8
1-5-1959	0.700	301.0	0.510	219.3
5-6-1959	—	—	0.180	77.4
19-6-1959	0.120	51.6	0.110	47.3
24-7-1959	0.530	227.9	—	—
21-8-1959	0.500	215.0	—	—
4-9-1959	1.190	511.7	0.800	344.0
18-9-1959	0.340	146.2	0.060	25.8
13-11-1959	1.250	537.5	0.490	210.7
4-12-1959	0.670	288.1	0.670	288.1
18-12-1959	0.470	202.1	0.280	120.4
22-1-1960	0.680	292.4	0.540	232.2
11-2-1960	0.300	129.0	0.280	120.4
19-2-1960	0.220	94.6	0.330	141.9
18-3-1960	—	—	0.450	193.5
8-4-1960	1.320	567.6	1.220	524.6
13-5-1960	0.542	233.1	0.463	199.1
15-7-1960	0.203	87.3	0.225	96.8
29-7-1960	0.736	316.5	0.483	207.7
2-9-1960	0.252	108.4	0.506	217.6
23-9-1960	0.269	115.7	0.335	144.1
28-10-1960	0.522	224.5	0.392	168.6
25-11-1960	0.398	171.1	0.141	60.6
16-12-1960	0.185	79.6	0.543	233.5
30-12-1960	1.348	579.6	—	—
6-1-1961	0.539	231.8	0.544	233.9
27-1-1961	0.713	307.0	0.467	200.8
24-2-1961	0.185	79.6	0.274	117.8
28-4-1961	0.380	163.4	0.296	127.3
2-6-1961	1.927	828.6	1.338	575.3
29-12-1961	0.520	223.6	—	—
19-1-1962	0.590	253.7	—	—

TABLE 9

Average annual production in mg C/m³/day

Year	Station 0		Station I		Station II		Station III		Station IV		Station V	
	S	B	S	B	S	B	S	B	S	B	S	B
1958	218.0	—	—	—	—	—	—	—	—	—	—	—
1959	192.7	222.7	179.1	101.9	121.8	145.1	278.9	197.4	251.7	174.2	251.6	213.1
1960	222.6	214.4	185.6	87.7	182.1	120.6	183.6	181.1	177.4	204.5	230.7	195.4
1961	—	—	177.0	211.9	382.2	242.1	144.0	177.3	241.0	329.4	251.0	251.0

S—Surface B—Bottom

Table 10

Organic production values for a few selected areas

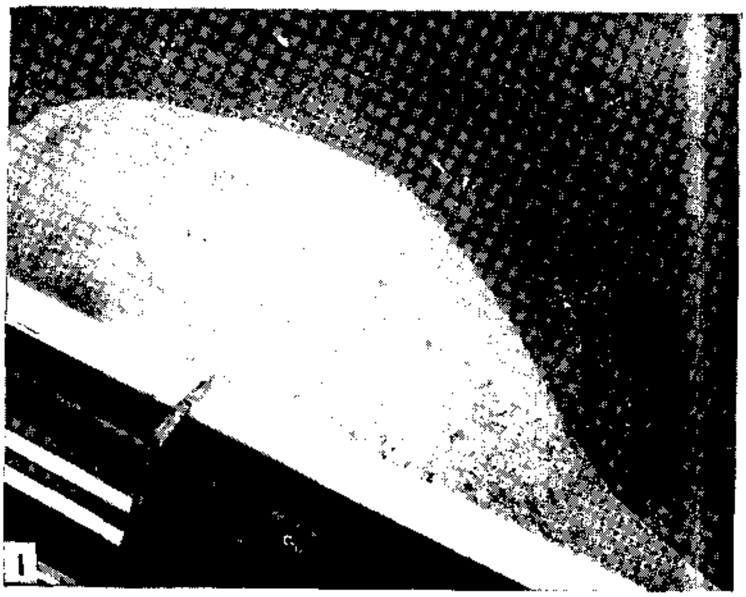
Location	Primary Production			Method	Reference
	mg C/m³/day	mg C/m²/day	g C/m²/year		
English Channel ..			84	P consumption	Atkins, 1923
			98	Change in CO_2	
			60	,, ,, O_2	
			70	,, ,, P	Cooper, 1933
			88	,, ,, N	
			7	,, ,, Si	
			5	,, ,, Ca	
North Sea ..		500		C^{14}	Steemann Nielsen, 1954
North Sea ..		200 - 1000	55 - 81	Phosphorus balance	Steele, 1956
Barents Sea ..			170 - 330	P consumption	Kreps & Verjbinskaya, 1932
Long Island Sound ..	20 - 410		600 - 1000	O_2 production (gross)	Riley 1941a.
Georges Bank ..	230	950		-do-	,, 1941b.
Galathea Station 139—Walvis Bay	6600	3800		C^{14}	Steemann Nielsen, 1954
W. Sargasso Sea 15 miles S.E. of Bermuda			103-165	Chlorophyll radiation	
			58 - 77	C^{14}	Menzel & Ryther, 1961.
Gulf of Mannar—Inshore	204 (Average for a year) 0 - 829 (Range)			O_2 production (gross)	Present paper.
-do- -do-	18 - 298 (Range obtained during a few random experiments)			C^{14}	,, ,,

TABLE 11

C^{14} experiments in Gulf of Mannar

Date	Station		Production in mg C/m³/day
21-12-1960	Mandapam : Inshore	S	265.6
,,	,,	B	127.7
25-6-1961	Keelakkarai	S	166.2
,,	,,	B	80.3
9-8-1961	Tuticorin (Devil's pt.)	S	89.4
,,	,,	B	68.2
10-8-1961	Tuticorin : 25 fathom line	S	237.1
,,	,,	10m	252.6
,,	,,	20m	51.1
,,	,,	30m	33.8
,,	,,	45m	3.4
14-8-1961	Tuticorin (Pinnakkayal)	S	202.5
,,	,,	10m	65.3
,,	,,	20m	23.7
28-11-1961	Mandapam : Inshore	S (F.N.)	297.9
,,	,,	B	43.7
,,	,,	S (D.B.)	2.5
,,	,,	B ,,	1.2
,,	,,	S (A.N.)	73.3
,,	,,	B ,,	36.7
4-12-1961	Mandapam (Off Pooma channel)	S	18.3
,,	,,	10m	122.6

A.N.—Afternoon D.B.—Dark bottle. F.N.—Forenoon.



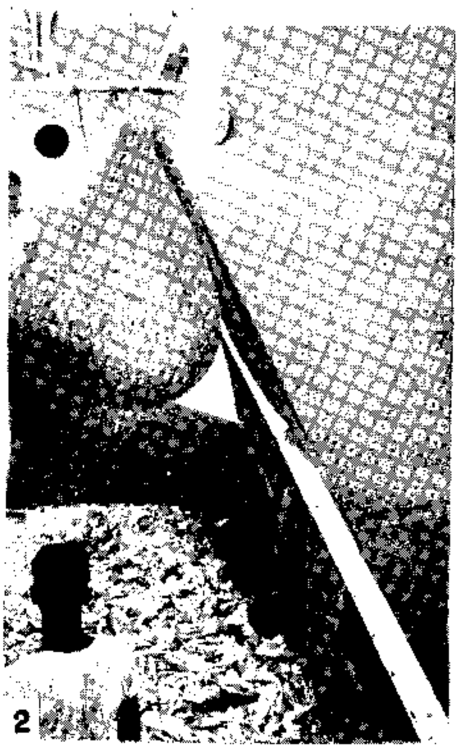


PLATE I (Figs. 1-3). Exploratory trawling by R. V. *VARUNA* on 5-2-63. 1. Cod end of the trawl with the catch alongside the ship ; 2 and 3. Discharge of the catch amounting to 3.5 tonnes.