PRIMARY PRODUCTIVITY IN THE INDIAN SEAS

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PRIMARY PRODUCTIVITY IN THE INDIAN SEAS

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C O N T E N T S

FOREWORD

The primary production in the sea is one of the most fascinating problems in marine biological research. With the introduction of the radio-active Carbon isotope (C^{14}) in the study of marine productivity, these investigations have gained greater significance and wide popularity among fishery scientists. Though the relation between primary production and fisheries is a complex one, the two lines of study are however complementary and hence give some insight into the quantum of potential resources. The hypotheses regarding the essential relationship between primary production and the potential resources of an area can be tested from studies on a small or isolated fishery. The results of the early investigations conducted by the Central Marine Fisheries Research Institute, Viz., those in the inshore waters of Mandapam, bear ample evidence of the same. The Institute's programmes on such productivity studies have subsequently been expanded to include the inshore waters of both the west and east coasts of the country, as also the waters surrounding Laccadives and Andamans. These have yielded significant results and it has been possible to make an assessment of our potential resources.

In this Bulletin Shri P.V. Ramachandran Nair has reviewed the results of primary production work conducted in the seas around India and also included a brief account of the techniques in the estimation of productivity parameters. I have much pleasure in recording my appreciation of the work of Shri Nair presented in this Bulletin and offer my thanks to him and all others responsible for bringing out this publication. It is hoped that this Bulletin will serve as a useful reference work to those interested in this discipline.

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Mandapam Camp,
Oct. 22, 1970.

I. INTRODUCTION

Production of organic matter by phytoplankton is of utmost importance because it initiates the whole marine food chain, which terminates in the larger fishes and sea mammals. The fundamental process in the production of organic matter can be given by the following eqauation:

$$6\ CO_2 + 6\ H_2O \qquad C_6H_{12}O_6 + 6\ O_2$$

The prime synthesisers are the plankton algae found in the upper layers of the sea where there is sufficient light for photosynthesis. Therefore a measure of the standing crop and rate of production of plant material is of greatest importance in fisheries research just as livestock raisers need a knowledge of the pasture conditions.

The word production has been used synonymously with standing crop. But there is a sharp distinction between the two, although in nature there is rather a high correlation between the standing crop of phytoplankton and primary production. Eventhough considerable amount of information was available on the standing crop measurements at different regions of the India seas, no data were available on the production of organic matter until the Danish *Galathea* Expedition laid the foundation by the introduction of radio-active carbon (C^{14}) in the study of primary production and made measurements in the equatorial part of the Indian Ocean and in the Bay of Bengal (Steemann Nielson, 1952: Steemann Nielsen and Jensen, 1957).

In view of the importance of productivity studies in fisheries research, Central Marine Fisheries Research Institute initiated the investigations in 1957 in the inshore waters of Mandapam. To begin with the well-known light and dark bottle technique was used. Later, with a consignment of carbon-14 from the International Agency for C^{14} determination, Charlottenlund, Denmark, data were collected from different regions in the Gulf of Mannar and Palk Bay. 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 (Prasad and Nair, 1960 & 1963). Gradually with procurement of counting equipment and radio-isotope from the Atomic Energy Establishment, Trombay, studies were extended to the south-west coast of India and Laccadive sea. During the International Indian Ocean Expedition considerable amount of data was collected by the participating countries in different regions of the Indian Ocean, the reports of which are being published. This review is aimed at bringing together all the available information on the productivity and related factors in the Indian seas, now scattered through various publications as well as in unpublished from into a consolidated whole so that it will form an incentive and a guide for further work.

II. METHODS FOR MEASURING PRIMARY PRODUCTION

The rate of primary production can be measured either directly or indirectly by estimating the standing stock of phytoplankton and using a conversion factor. For direct estimation the production is either measured experimentally by enclosing water samples in bottled or by utilizing difference in the water masses during a certain period by measuring some property at the start and the end of this period.

All of the pioneer work concerning productivity was based on the standing stock. In the beginning only catches taken with tow nets were used for estimating phytoplankton. But as is now recognised net method may give quite erroneous results with regard to the amount of plankton found in the sea as the mesh of the net is too large to retain considerable part of the planktonic algae found in the sea.

In recent years the concentration of pigments active in photosynthesis, primarily chlorophyll has been employed as an index of the standing stock of plants and also as a means of estimating the rate of primary production (Ryther and Yentsch 1957). Consumption of carbon dioxide (Atkins 1922) or nutrient salts (Steele 1958, Cooper 1958) as

a means of measuring primary production have also been used. Daily variation the oxygen content of the water between morning and afternoon has also been used as a means of estimating the organic production in certain marine areas (Fedosov 1958).

PHYTOPLANKTON STANDING CROP AND ESTIMATION OF CARBON

To measure the standing crop of phytoplankton the organisms suspended in the water must be concentrated first. It is possible by filtration centrifugation or sedimentation. Subsequently the number of organisms and its volume (/u^3/litre) may be determined or the organic matter estimated by chemical means.

In filtration techniques different materials are used. The net made out of bolting silk has remained as the tool for estimation of standing stock for about half-a-century. It is still being used in spite of the fact that considerably large quantities of nanno and ultraplankton are lost in sampling. Filtration by means of membrane filters which is then made transparent by oil has been found to be a better method but even in this some of the naked flagellates get destroyed.

Sedimentation technique introduced by Utermohl (1931) combined in inverted microscope is used by many workers for quantitative study of phytoplankton. From such standing stock measurements the organic matter can be computed using certain conversion factors (cf. Cushing 1958). The standard equivalent would be 1mm^3 algal volume = 0.10-0.125 mg. C.

PIGMENTS

The plant pigment content of phytoplankton assumes great importance in productivity studies because of the use of these compounds for estimating the primary product and gross photosynthetic potential. Either total pigments, total chlorophyll, or the single pigments may be measured. Pigment analysis primarily chlorophyll determinations, have been used in recent years (Krey 1958). The spectrophotometric technique introduced by Richards with Thompson (1952) with subsequent revisions Parsons and Strickland 1963) have long replaced the less accurate standardisation procedure of visual matching of pigment extract with standard of nickel sulphate and potassium chromate (Harvey, 1934).

The conversion factors as given by Cushing (1958) for plant pigment unit and chlorophyll are as follows:

1 P.P.U = 3.9 – 5.2 /ug. Carbon

1 /ug. Chlorophyll = 13.6 – 17.3 /ug. C.

Using Harvey's (1934) method Subrahmanyan (1959) made quantitative determinations of the standing crop of phytoplankton of the west coast. He found that the standing crop in terms of carbon varies from 0.06 g to 12.28 g over a metre square area of the sea surface with the highest values during the south-west monsoon. From these measurements he concluded that the west coast of India is one of the highly productive regions of the world in general and the tropics in particular. But the open ocean presents a different picture.

During the IIOE considerable amount of data on pigments were gathered from the oceanic regions of Arabian Sea and Bay of Bengal. According to Humphrey (1966) the amounts of chlorophyll in a water column under $1m^2$ are of the same order of magnitude for all oceans, although in the Indian Ocean the concentration of chlorophylls per litre of water does not reach the highest values found in the Atlantic and Pacific Oceans. However, extremely high values have been observed in the upwelling regions associated with Somali Current. [Radhakrishna (1969) observed an average value of 19.50 mg/m^2 for chlorophyll *a* (range 7.6 – 30.35) and 43.34 for chlorophylls a+ b+c (range 21.61 – 68.00) in the shelf waters of south-west coast of India during the post-monsoon months and carbon chlorophyll a ratio of 3.5 (average)] Shah (personal communication) found for an inshore station off Cochin that chlorophyll *a* values range between almost nil and about 8 mg/m^3 in the surface and between nil and 6 mg/m^3 at 15 metre depth. For the water column (0-16 m) pigments range between approximately 2 and 210 mg/m^2. If the variation in the total pigment content is considered then it is seen that June to October are the rich months and November to March the poor months, the average values being about 150 mg/m^2 and 20 mg/m^2respectively. In January which is the poorest month there was about 5-10 mg/m^2.

The distribution of the chlorophylls *a*, *b*, plus *c* and carotenoids in percentage concentration as given by Radhakrishna (1969) is shown in Fig. 1. He observed that the 3 chlorophylls varied parallel to the general trend of carbon assimilation at the various light intensities. Chlorophylls *c* was greater than *a* at the surface, but the carotenoid concentration was the highest. At 50% depth, concentration of *a* was the highest followed by *b* and *c*. The carotenoids were low at this depth. The high rate of photosynthesis here was accounted for by the three chlorophylls together and not a alone. At 25% depth, *a* decreased, while *c* and carotenoids increased . A further increase in *c* and carotenoids and a corresponding decrease in *a* and *b* was seen at the 10% depth. At the 1% depth *a* plus *b* formed only 23%. While *c* was 27% and carotenoids formed 50% of the total pigment content.

Mean values for integrated total pigment from 0-200 m is given by Mc Gill and Lawson (1966) (Table 1).

Table 1
Mean values for total pigment

Area	Total pigments from 0-200 m (mg/m^2)	
	1963	1965
North of Equator	54.29 $\pm$ 4.36	31.06 $\pm$ 2.69
South of Equator	33.52 $\pm$ 3.22	36.12 $\pm$ 3.46
Total area	44.19 $\pm$ 5.16	33.37 $\pm$ 3.56

ESTIMATION OF PHYTOPLANKTON PIGMENTS

An account of the spectrophotometric method for the measurement of chlorophyll is given.

Equipment and apparatus : (1) Spectrophotometer, (2) Filtering Unit, (3) Stoppered graduated centrifuge tubes of 15 ml capacity having both glass and polyethylene stoppers, (4) One 300 ml plastic wash bottle.

Reagents :

1. 90% Acetone: 100 ml of distilled water is pipetted into a litre volumetric flask and acetone (preferably redistilled) added to make up the volume to exactly 1000 ml and transfer into a plastic wash bottle.

Every time freshly prepared 90% acetoene is to be used for better result.

2. **Magnesium carbonate ($Mg C O_3$) Suspension :** This is prepared by adding 1gm of finely powdered magnesium carbonate (A.R) to 100 mil of distilled water in a stoppered bottle. Shake vigorously before adding it into the sample.

Sampling : Sea water samples 500 ml to 5 litres from any part or zone of the sea under observation are collected in polythylene bottles. For pigment analysis samples collected by means of ordinary plankton net (mesh size about 40 ^{u}) are quite inadequate as a considerable volume of photosynthetic organisms under this size escape. Larger zooplankton are removed from the sample by filtering through a small piece of 0.3 mm mesh size nylon netting.

Phytoplankton are separated from the sea water either by centrifuging or filtering through various types of filters preferably Millipore filters. For the separation, filtering is found to give better result.

From the filtrate, required volume is measured by a polyethylene cylinder into a polyethylene bottle. Two or three drops of magnesium carbonate suspension are added. This promotes effective filtration, facilitates centrifugation and prevents acidification of the extract and thus retard the formation of phaeophytin pigments.

Procedure: Shake the sample vigorously and invert the polyethylene bottle containing the sample into the funnel of the filtering unit fitted with a 47 mm diameter Millipore filter, the pore size of which is noted.

Drain the filter thoroughly under section. Take the filtrate and trim the excess periphery.

If the filters are to be store, fold them so that the disc containing plankton come innermost and keep them in dark in a desiccator at less than 20^{o} C.

Place the filter in a 15 ml stoppered graduated centrifuge tube. Add approximately 8 ml of 90% acetone. Stopper and dissolve the filter by shaking the tube vigorously. Allow the pigments to be extracted by placing the tube in a refrigerator in complete darkness for about 10-20

hrs. Frequent shaking ensures rapid extraction.

Warm up the tubes in dark nearly to room temperature. Add 90% acetone to make up the extract to 10 ml. Replace the glass stoppers of the centrifuge tubes by plastic stoppers to prevent breakage during centrifugation. Centrifuge the content of the tubes for 10 minutes at 3000 to 4000 r.p.m.

Measure the extinction of the solution spectrophotometrically against a cell containing 90% acetone at 7500, 6650, 6450, 6300 and 4800 A.

Calculation: Concentration of pigments in sea water is calculated from the equation

mg pigment/m^3 =

C = Volume obtained from the formula given below
V = Volume of sea water filtered in litres

Formulae (Parsons and Strickland 1963)

C/V

C (chlorophyll a) = $11.6E_{6650} - 1.31.E_{6450} - .14E_{6300}$
C (chlorophyll b) = $20.7E_{6450} - 34E_{6650} - 4.42E_{6300}$
C (chlorophyll c) = $55E_{6300} - 4.64E6650 - 16.3E_{6450}$
C (plant carotenoids) = $4.0E_{4800}$, if crop predominantly Chlorophyta or cyanophyta
C (plant carotenoids) = $10.0E_{4800}$, if crop predominantly Chrysophyta or Pyrophyta

(E = the extinction values at wavelengths indicated, measured in 10-cm cells after correcting for a blank)

Determination of blank:

(1) Cell – to cell blanks: Fill both spectrophotometer cells with 90% acetone and find the "cell-to cell" blank of the sample cell against the reference cell at all wavelengths used.

(2) Turbidity blanks: The extinction from colloidal material present in the extract caused buy Millipore filter depends on the wavelength of light used. The extinction at 7500 A is corrected for any cell-to cell blank at this wavelength and the resulting extinction (E_b) is multiplied by a

factor 'f' to give the turbidity blank extinction to be used with spectrophotometer reading at other wavelengths.

Total blank correction = cell- to- cell blank + (f x E_b)
where 'f' has the value shown below :-

Wavelength A^0	' f '
6650	1
6450	1
6300	1
5100	2
4800	3

Estimation of carbon Production from chlorophyll concentration

Production can be estimated from radiation, transparency and chlorophyll using the equation.

$$P = \frac{R}{K} \times C \times 3.7$$

C = g Chlorophyll /m^3

P = Photosynthesis in g carbon/m^2/ day

R = Relative photosynthesis

k = Extinction coefficient of visible light in the water columns/metre

The value 3.7 g is the quantity of carbon assimilated per hour at light saturation for each g of chlorophyll (Ryther and Yentsch 1957). Production in g carbon/m^3 at particular depth is calculated from the expression

Pd = Rd x Cd x 3.7

Rd = Relative photosynthesis at depth (d)

Pd = Photosynthesis in g carbon/ m^3/ day at depth (d)

Cd = g xhlorophyll/m^3 at depth (d)

OXYGEN TECHNIQUE

The experimental method of using oxygen production is the well-known light and dark bottle technique introduced by Ggaarder and Gran (1927). In this, samples are collected from the various depths in bottles with glass stoppers. Some of the bottles are used for determining the concentration

The other bottles are again lowered to the depths from where the samples came and kept there for 24 hours fixed to an anchored buoy. In the bottles made dark by wrapping with black materials, only respiration takes place. The oxygen content in the light bottles minus that in the dark bottles represents the *gross* production. The oxygen content in the initial bottles minus that in the dark bottle represents the respiration of all of the organisms present. The oxygen content of the light bottle minus that of the initial bottle represents *net* community production.

$$\text{Production (mg C)} = \frac{O_2\,(\text{ml}) \times 0.536}{PQ} \quad \text{or} \quad \frac{O_2\,(\text{mg}) \times 0.375}{PQ}$$

where PQ is taken as 1.25.

Various limitations and possible sources of error with the oxygen method are discussed by Steemann Nielsen (1958) and several other authors (Strickland, 1960).

The lower limit of the oxygen technique depends on the sensitivity of the winkler method. The precision is generally less in coastal water. However in productive coastal water this technique is normally applicable while it is not useful for measuring the productivity of oceanic water as the rate of production will be too low. The carbon-14 technique on the other hand, because of high sensitivity, is widely used to determine oceanic productivity.

CARBON-14 TECHNIQUE

Radioactive tracers have revolutionised the methods used in many biological investigations including oceanic primary production. Carbon -14 was used for measuring the primary production in the sea for the first time by the Danish *Galathea* Expedition. The technique was described by Stemann Nielsen and Jensen (1957). Different details and minor modifications have been given by several authors (Doty & Oguri 1958 & 1959; Sorokin 1958; Dyson *et. al*. 1965, Arthur & Rigler 1967). Recently a critical review of the techniques have been published as an IBP Mannual (Vollenweider (Ed) 1969) which deals with the fundamental issue of primary production.

The practical application of C^{14} technique in field work is relatively simple. A solution with definite amount of $NaH^{14}CO_3$ in sealed ampoules is pipetted out and is added to sea water samples collected from different depths before an experiment. The content of total CO_2 in the water is determined or estimated. After exposure of the samples for definite period either from sun rise till noon or from noon to sun set at the same depth (*in situ*) or in deck incubators under neutral density filters simulating the light conditions at the particular depths (simulated *in situ*) or constant light with an apporoximate intensity of 20 klux (tank method) (Plate II & III). The samples are then filtered under suction on to Millipore or membrane filters which are then dried and counted. The counter used in Central Marine Fisheries Research Institute is a 2π gas flow counter with a counting efficiency of 61.1% (Naiz 1966). Some details of the technique are given below:

The isotope : C^{14} emits only beta Particles. The half thickness (d ½) is about 3 mg/cm^2**,** R is about 30 mg/cm^2 and the half-life period (t ½) is about 5,600 years. Each ampoule contains one ml of a sterilized solution of $NaHCO_3$+$NaH^{14}CO_3$. The pH being 9.5 the ampoules can be stored for any length of time. The strength of C^{14} is 4/μC per ampoule for International Agency ampoules and 5/μC for Central Marine Fisheries Research Institute ampoules. (The International Agency for C^{14} Determination, Charlottenlund, Denmark arrarnges to send C^{14} ampoules and filters and also counts the samples). As variations occur in the strength of the mother material ($Ba^{14}Co_3$) and as variations may happen during the procedure it is necessary to determine the strength (counts/minute/ampoule) of every portion. (See Calvin et al 1949 for details).

The membrane filter : The diameter of the filter is 35 mm. The average diameter of the pores is 0.4/μ. (max. 0.8μ). The filter is soluble in acetone, ether etc. It is necessary to use a forceps when handling the filters. As the membrane filters may burst when they are exposed to pressure it is necessary to keep an ordinary filter paper underneath and moisten it.

The membrane filters shrink when drying. So it is necessary to keep these filters in a fixed position when drying in order to have a constant area. Special holders are provided by the Agency.

The Millipore filters have the advantage over the membrane filters and they do not shrink when drying. They are of 24 mm dia. and the side with the grid is used for filtration supported by porous pad. The HA variety used in the Institute has an average pore size of 0.45µ.

The water samples to be used for the experiments should be taken with a glass, plastic or other type of non-metallic, non-toxic sampler.Insulated water bottle or Van Dorn sampler is used on board the vessel (Plate 1). The experimental bottle is filted half with water. The neck of the ampoule is usually filled with the tracer liquid, so this must be replaced in the corpus of the ampoule. The neck of an ampoule is snapped with a finger till all the liquid is in the corpus. With a glass knife a mark is cut in the narrow part below the neck after which the neck is craked. The liquid is pipetted from the corpus into the bottle and the nack and the corpus of the ampoule are rinsed once. The bottle is filled and closed tightly by the glass stopper. If several bottles are to be used in the same experiment, take care that they are exposed to the light simulataneously. It is not advisable to use greater concentrations that l ampoule per 25 ml water. For routine work 50 or 100 ml bottles are usually used.

Filtration: The membrane filter is placed in such a way that the filtrations takes place on the side opposite that where the code number is written. A moistened filter paper is placed under the membrane filter in order to support it, after which the bottom piece is screwed on the apparatus (Plate). The long screw at the top piece near the manometer is removed, and the water from the experimental bottle is poured into he apparatus by a funnel. The screw is placed again tightly and pressure established (max. 1.5 atm.). The filtered water is collected in a dish or bottle and is carefully thrown away. The same is the case with the empty ampoule.

After filtration the pressure is released by loosening the screw on the top. The bottom piece is unscrewed and the membrane filter is placed on a dry filter paper for a few minutes (in order to avoid forming of NaCl crystals). The membrane filter is dried in special holders for 6-12hours. When dry the filters are stored. For filtering 6 samples simultaneously a manifold filtering unit is used with a suction pump connected through a Buchner flask with a trap between the pump and flask

to prevent to accidental flow of filtrate into the pump (Plate V). The Millipore filters after filtration are fixed with a little vaseline in numbered grooves on a perspex holder and dried over silica gel. The following data are also obtained for each experiment:

1. Temperature of the sea water
2. Salinity of the sea water (from water from the open ocean it is sufficient to designate "ocean water").
3. Temperature during the experiment
4. Duration of the experiment.

Determination of C1 % (S%) is necessary for computation of total CO_2 in sea water. In brackish water and fresh water, the total CO_2 has to be determined.

Estimation of total CO_2 in solution in oceanic waters for experimental work with C^{14}: The estimation of CO_2 in sea water is important in productivity studies due to the significant role of CO_2 in the process of photosynthesis. In sea water CO_2 exists either in its free form or as bicarbonate and carbonate ions. The total CO_2 in solution is oceanic waters depends upon pH, salinity and temperature. Its concentration bears a rough inverse relation to the pH. Its value in solution at a particular pH, changes with change in salinity, nearly in direct proportion between 27 and 38% S and at a particular pH decrease 1% per rise of 1^oC. A convenient and commonly adopted method which gives sufficient accuracy for physiological experiments is given.

Estimation from total alkalinity and pH :

Equipment: pH meter

Reagents: (1) Standard Buffer solutions of two different pH (pH 4 and pH 6.87 both at 20 to 25^o C).

Buffer having pH. 6.87 is prepared by dissolving 3.4 gm of potassium dihydrogen phosphate (KH_2PO_4) and 3.55 gm of anhydrous disodium hydrogen phosphate (Na^2HPO_4) in distilled water and making up the volume to 1000ml in a volumetric flask. The diluted solution should be stored in tightly stoppered polythelene bottle to prevent evaporation. If a few drops of chloroform are added, this can be used for a few weeks but should not be used after bacterial growth.

Buffer having pH 4.00 is prepared by dissolving 10.21 gm of potassium hydrogen phthalate (AR) ($KHC_8H_4O_4$) in distilled water and making the volume to 1000 ml in a volumetric flask. Store in tightly stoppered glass bottle.

(2) Standard 0.01000 N Hydrochloric Acid

Add calculated amount of distilled water to hydrochloric acid of slightly greater concentration the normality of which is known, to bring is to precisely 0.10 N. Take aliquot by pipette and dilute to tenfold in the measuring flask.

Procedure: Set the temperature compensator of the pH meter corresponding to the temperature of phosphate buffer (pH 6.87) which should be between 20 and 25°C and standardize the instrument according to the maker's instruction. Meassure the pH and temperature of the sample after 3 to 5 minutes imersion of the electrodes adjusting the temperature compensator of the meter to the solution temperature just before the final reading is taken.

Pipette 100 ml of the sample to 25 ml of standard 0.01000 N hydrochloric acid taken in a wide mouth polythelene serew-cap bottle. Stopper the bottle and mix the solution thoroughly. Warm the solution to room temperature and measure the pH with the pH meter which has been standardised with phthalate buffer.

The pH will be usually less than 4.0 but for the oceanic waters of salinity greater than 33% where it is above 4.0. For the latter again add 5.00 ml of 0.1000N acid from a pipette, mix the solution and measure the pH.

Calculation:

When pH is between 2.8 and 4.0

Total alkalinity = 2.500 –(1250 aH/f)

and when it is above 4.0

total alkalinity = 3.00 – (1300 aH/f)

The value of aH corresponding to the measured pH value can be found from the table given (Appendix I.) The pH must lie between 2.8 and 4.0. Also find the value of 'f' from the table given (Apendix II) according to the salinity and pH value

From total alkalinity, carbonate alkalinity can be calculated.

Carbonate alkalinity =total alkalinity –A (milliomoles/1)

Find the value of 'A from the given table (Appendix III)

Total carbondioxide content in millimoles/1 is obtained when

Carbonate alkalinity is multiplied with the value of F_T which is obtained form Appendix IV.

Total carbondioxide content = carbonate alkalinity. X. F_T

When the result is multiplied by 44, total CO^2 content in mg/l is obtained.

Instrumentation for counting : This instrumentation for counting the filters is the Gas flow proportional counter designed by the Electronics Division of the Atomic Energy Establishment, Trombay (BARC) and now manufactured on a commercial scale by the Electronics Corporation of India (Plate VI) The gas used is 'Burshane'.

It consists of a High Voltage Unit, Pulse Amplifier, Scaler, Pre-set Timer and a Windowless counter with pre-amplifer.

H.V. unit is the type HV 202 for providing electronically regulated high voltage variable from 2KV to 5KV in steps of 20 volts at a maximum load of 200 u Amps.

The scaler BS 300 comprises of a wide band input amplifier, a calibrated pulse height Discriminator, eight Binary Scaling stages providing a total scaling factor of 256 with a register drive circuit. In the Scaler DS 370 the scaling process is accomplished by three single pulse dekatron glow tubes. So interpolation is easy. Both these scaler can be used independently if counting rates are low. If the input pulse rate exceeds 10, 000 pulse/sec in the Decade Scaler or 2500 pulses/sec in the Binary Scaler cascading of one with the other should be done. The following connections may be checked before operating the instrument.

1. Use the power cable with teflon insultation for the E.H.T.
2. Connect the output of the preamplifier to input of Pulse Amplifier.
3. Connect the out put of the Amplifier to the input of the Scaler.

4. Connect the Preset Timer to the Scaler (When Timer is used the COUNT switch of scaler should be off).
5. For cascading one scalar with the other, the shielded cable terminated at one end in a phonoplug is inserted into the jack marked OUTPUT at the back of the instrument. Insertion of the plug automatically cuts off the mechanical register. The other end with a coaxial cable plug is connected to the second scaler.

When using two scalers in cascade, the 'COUNT' of the second scaler should be kept permanently on and the counting operation controlled by the 'COUNT' of the Decade Scaler.

The operational particulars are follows:

Amplifier
1. Keep the gain control maximum,
2. Keep the differentiation time constant at 5μsec.

Scaler
1. Keep if possible 5 volts Discriminator Bias on the scaler.
2. Set the SELECT SCALE suitably,

E. H. T. Put the FII on and green light glows. Wait for about 5 minutes and then put on E.H.T. Start always from low value on E.H.T.

Note:
1. Always flush the gas for about 5 minutes before taking observation.
2. Tight counter properly to avoid leakage.
3. Never leave the counter loaded with the source when not in use.

The counting will start the moment COUNT is switched on (START if the Pre-set Timer is connected). After the counting run switch off COUNT. (Pre-set Timer stops when register comes to 0000).

To read the scaler multiply the counts registered in the counter by the scale factor and add to the product the sum of lit up neons.

Determining the working voltage : Using a standard source counts are taken at different voltages. When increasing the high voltage for each step the increase in the count rate can be observed. Plot the curve of counts/minute versus the voltage. The region where in the count rate is substantially constant with change in voltage is the *Plateau*. At the high end of the plateau a region will be reached were a slight increase in voltage will cause a large increase in the count rate. This is the region of continuous and so high voltage is to be reduced

immediately.

After the curve has been plotted the proper operating voltage for the counter can be selected. This voltage is approximately one-third to half of the total plateau region.

Background: A certain portion of any radioactivity measurement is not attributable to the radioactive sample being measured but comes from other sources. This portion of the measurement called the background arises from local gamma radiation from minute traces of naturally occurring radioactive substances. Cosmic radiation itself accounts for as much as one half of the total background counting rate. Though the error due to background may be negligible at high counting rates, it may form a source of considerable error at low counting rates. Since background can vary greatly, it must be measured separately and substracted from any measurement upon which it will have an effect.

Other sources of error is due to the efficiency of set-up and random distribution of pulses. Identical counting runs on the same sample may yield different number of counts on the scaler. This discrepancy is due to the random occurrence of disintegrations in the radioactive source. In general the probable error is $0.67\ \sqrt{N}$ where N is the total number of counts recorded rather than the total time involved. So for low count rates in the filters more time is required to establish the desired accuracy.

Calculation: The rate of production in mg C/m^3 / day is calculated **(**for in *situ* or simulated *in situ* experiments) using the formula:

$$\text{Rate of production} = \frac{\text{Net Activity}}{\text{Added Activity}} \times \frac{\text{Total } CO_2}{\text{Day of Incubation}}$$

where a day is assumed to be the period from sun rise to sun set.

For constant light incubator the production rate is obtained in mg C/m^3/hr by the formula:

$$\text{Rate of production} = \frac{\text{Net Activity}}{\text{Added Activity}} \times \frac{\text{Total } CO_2}{\text{Hours of Incubation}}$$

The total CO_2 is assumed to be constant in oceanic waters 90 mg CO_2/1 (24, 500 mg C/m^3). But in inshore waters etc. it might vary.

In such cases total CO_2 is calculated from carbonate alkalinity and a quotient derived as a function of pH and temperature for different salinities (Harvey 1957) as indicated earlier.

Some minor correction are to be introduced for short-term experiments. A correction factor of 1.06 is required to obtain rate of gross production and a factor of 0.96 to obtain rate of net production (Steemann Nielson, 1964). Another correction is the dark fixation of CO_2 by phytoplankton and other organisms.

For the determination of production under one square metre of sea surface there are certain modifications of the method.

(1) *In situ* method to be conducted at different depths. The intensity of photosynthesis at different depths is plotted graphically and the area to the left of the curve is calculated.

$$\frac{f}{100}\left[(d_1 - d_0)\frac{(a+b)}{2} + d_2 - d_1\frac{(b+c)}{2} + \ldots\right]$$

elsen and Jensen (1957) have derived an empirical formula for experiments conducted in tank under constant light intensity. Production per m^2 per 24 hours:

$$\frac{(2a + 2b + C).d.c}{5.2} \text{ mg C}$$

Where a is the photosynthesis in mg C/hour/m^3 at 18000 lux in surface water. b is that in water from a depth with 10 per cent of surface light c that in water from a depth with 1 per cent of the surface light

d is the depth in m at which is 1 per cent of the total quantity of blue and green light at the surface and e is the number of hours from sunrise to sunset.

(3) Dyson *et. al*. have given the formula :

Column production =

Where d_0, d_1, d_2 are the depths sampled; a, b, c are the respective production rates; f is a factor for converting the units to production per day. When incubation is *in situ* or simulated *in situ*, f is 1. When incubation is under a constant artificial light it is 10, as the daily rate is assumed to be 10 times the hourly rate.

Though *in situ* experiments are the best it is not always possible to conduct it for a number of stations in the same cruise. Hence simulated *in situ* experiments and constant light incubator experiments are conducted to save time. However these results are to be calibrated.

Standardization: In order to determine the "added activity" in the ampoule the best method available seems to be the biological method developed by Steemann Nielsen (1965) and the scintillation technique developed by Jitts and Scott (1961).

In the biological method of standardization cultures of *Chlorella* are allowed to assimilate the total amount of CO_2 by working at a pH of about 4.0 where all CO_2 is in the form of the free CO_2 and by starting at CO_2 concentration of about 0.5%.

In the scintillation counting technique the efficiency of the counter is determined by first counting thin-films of labelled perspex with the same geometry as phytoplankton samples, then measuring the absolute activity of the films by liquid scintillation counting. The absolute activity of C^{14} stocks is also measured by scintillation counting. The zero thickness activity of C^{14} stocks is calculated from the absolute activity and the counter efficiency.

Table 2 gives the c.p.m. and the absolute activities (d.p.m.) of 19 filters. It may be seen that a mean counting efficiency value of 61.1% with a standard deviation of 2.7 has been obtained.

Table 8

Zero thickness counting efficiency of proportional counter

Serial No. of Filter	c. p. m.	Absolute activity (d. p. m.)	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

Nair (1966) found that there is very close agreement between those two techniques while the Ba CO_3 Self-absortion curves give highly variable values

Table 3

Zero thickness activities of ^{14}C stocks with the gas flow Proportional counter

Stock	Added activity by biological method	Added activity calculated according to Jitts & Scott
AEET Stock I	6.33×10^6 c. p. m.	6.96×10^6 c. p. m
AEET Stock II	7.00×10^6 ”	6.90×10^6 ”
Mean of AEET Stock	6.67×10^6 ”	6.93×10^6 ”
International Agency Stock	4.55×10^6 ”	4.50×10^6 ”

Comparison of Oxygen and C14 techniques : Oxygen and C14 Techniques may not always yield concordant result 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 (Fogg 1969). Comparisons using laboratory cultures or natural samples when there is an abundance of phytoplankton show close agreement with a photosynthetic quotient of little more than unity (Prasad & Nair 1962, Fogg 1963). But there may be great discrepancies between the results of the two methods when cells are sparsely distributed as in oceanic waters (Prasad & Nair 1962) or when cells are exposed to high light intensities (McAllister 1961). According to Fogg (1963) these discrepancies arise mainly from fixation of C^{14} by carboxylation reactions and from release of extra cellular products of photosynthesis (See also Fogg 1958).

It has now been established that oxygen method covering a period of 24 hours is quite reliable for productive coastal areas and C^{14} method because of its greater sensitivity is the only one that can be satisfactorily used in oceanic environment (see also, Steele 1961; Strickland 1961 & 1963; Steemann Nielsen 1960; Yentsch 1963).

Gross production and net production : To evaluate the primary production in natural habitat the size of gross production and the net production must be known. So the rate of respiration has to be determined. Steeman Nielsen and Hansen (1959) have described a method for measuring the rspiratory rate of autotrophic phytoplankton by means of C^{14} technique.A curve showing the rate of net photosynthesis as a function of light intensity is obtained. By extrapolation a rather precise rate of respiration can be deduced (Fig.2).

Gross production minus respiration equals net productions. Gross production is an intangible quantity, whereas net production is the real production of organic matter which is added to the environment and hence of real concern to the ecologist (Ryther 1956) as it is the potential source of energy which can be transferred to the next trophic level. Light and dark bottle method gives gross production and net community production. The rate of net production is always higher than the rate of net community production because the dark bottle correction for respiration includes that the bacteria, zooplankton and heterotrophic plants.

III. LIGHT PENETRATION AND PRIMARY PRODUCTION

One of the most obvious variable factors influencing primary production is the amount of solar energy 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. But the seasonal variability of the radiation factor *per se* is relatively unimportant in the Indian Seas.

The average daily radiation falling in the Cochin area falls appoximately within a range of 250-550 g cal/cm^2/day (Qasim *et. al.* 1968). Daily illumination and percentage occurrence of days in a year and average daily radiation have been given in Table 4 from Qasim *et. al.* (1968).

Table 4
Daily illumination and average radiation *

Daily sunshine, hours	10-12	8-10	6-8	4-6	2-4	0-2
Percentage occurrence of days in a year	31.2	20.2	15.1	9.6	8.5	15.4
Range in illumination (kilolux-h)	500-700	450-550	400-500	250-350	200-300	100-200
Avarage daily Illumination (kilolux-h)	600	500	450	300	250	150
Avarage daily radiation (g cal/cm^2/day)	626	522	470	313	261	157

* (From Quasim *et. al.* 1968)

For the production of matter only 0.02 to 2% incident radiation is being utilised or 0.1% on an average. The main reason for the low utilization of the light penetrating the sea surface is because the majority of it is absorbed by the water and particles of dead organic and organic material (Steemann Nielsen 1958 a). A high utilization of the incident light is possible only if the phytoplankton is concentrated on a shallow photosynthetic layer, when the light absorption by the water is reduced to the minimum. This accounts for the higher production rates in the coastal areas.

Plant growth occurs whenever photosynthesis exceeds respiration. The depth at which the two processes are equal is the compensation depth, which is a function of incident radiation and transparency of the water. Though it changes throughout the day, for practical purposes it is taken as the maximum depth at which plant growth takes place under clear skies and with the sun overhead. This is the euphotic zone which is reckoned as the depth to which 1% of the incident light penetrates. The depth of the euphotic zone can vary from less than a meter to over 100 meters depending on the suspended matter. And production rate per m^2 varies inversely proportional to the depth of euphotic zone (Steemann Nielsen, 1958) – Fig.3.

In coastal and inshore regions transparency is very variable. In Gulf of Mannar and Palk Bay the compensation depth is at about 6 m indicating a high quantity of suspended matter while on the west coast it varies from 14 meters on cloudy days to about 50-60 meters on bright days. Very near the coast it is about 15 meters. In the Laccadive Sea where the waters are clear blue it exceeds 90 meters.

For a high extinction coefficent of 1.0, the compensation depth is 5 meters, while a coefficient 0.04 shows a high transparency which is symptomatic of low productivity (Ryther 1963). In the turbid estuaries even higher extinction coefficients have been recorded –k = 1.37 and compensation depth 3m (Qasim *et. al*., 1968).

Measurement of light penetration: The apparatus used for measurements of the extinction coefficients is a Tinsley Lrradiance Meter. It consist of a deck cell mounted on gimbals and a sea cell mounted in bridle, a galvanometer and ratiometer which measures directly the ratio of the light intensities falling on the sea cell and deck cell which is expressed in percentage. Both the deck cell and sea cell are fitted with Megatron photocells 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 receives full 180^0 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 meters 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 ratiometer readings, r_{10} transmission ratio at 10 m and so on (Gall 1949). Table 5 gives the light penetration and extinction coefficients at two stations taken on the west coast.

Table 5

Ligh penetration and extinction coefficients

Date	Station No.	Position	Depths	Percentage of surface light	Extinction coefficient
4-6-1965	3109	$7^0$30´N	5	40	0.138
		$76^0$00´E	15	20	0.033
			25	10	0.026
			35	5	0.120
			45	1.8	0.110
6-1-1966	3331	$13^0$35´N	5	30	0.161
		$75^0$34´E	15	20	0.066
			25	12	0.026
			35	7	0.051
			45	4	0.069
			55	1.8	0.069

Secchi disc also is used for a rough measure of the depth of euptic zon. The transmission ratio at the depth of disappearence of sachi disc was found to be normally about 17%. In clearer waters it fills to 12%. Roughly 3 times the Secchi disc depth can be taken as the ephotic zone. (see Strickland 1958 for details on solar radiation)

IV. NUTRIENTS AND PRIMARY PRODUCTION

The availablility of nutrients is the other environmental factor which limits primary production. The essential nutrients are brought into the euphotic zone by the vertical mixing of the water column which is caused by wind wave action, processes associated with ocean currents and by upwelling of deep waters.

Reddy and Sankaranarayanan (1968 a) have given descriptive account of the distribution of phosphates, silicates and nitrates in the shelf waters of Arabian Sea along the west coast of India. According to these authors the vertical profiles of nutrients during the monsoon months indicate enrichment of coastal waters by the nutrients brought up from the subsurface levels. This process of enrichment is more intense towards the southern part of the west coast of India. Increased vertical stability of the waters particularly in the post-monsoon period keeps the nutrient levels low. In the offshore regions marked variations in the nutrient levels are observed in different seasons. But in the coastal region the seasonal variations in nutrient concentrations is relatively less because of the constant mixing of the entire water column. The integral concentration of phosphates in a 100 m column below a square metre of sea surface between Ratnagiri and Cape Comerin is 100 u-at. P/m^2 with a range of 70-130 u at P/m^2 (Panikkar, 1967). In the Arabian Sea the general level of plant nutrients in high, the nutrient rich water lies in close proximity to the euphotic zone, which is a potentially productive condition (Ryther *et al*., 1966).

On the other hand the nutrient concentrations in the Bay of Bengal is of a lower order compared to the Arabian Sea. The Andaman and Nicobar region, however, is found to have a high concentration of phosphates (Sankaranarayanan and Reddy, 1968). The absence of large-scale upwelling is presumed to be the main cause for the lower nutrient level of Bay of Bengal.

A direct correlation between primary production and nutrient salts was observed by Kabanova (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 nitrates were absent and in 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 magnitude of primary production is influenced primarily by the availability of nutrients as the other conditions are never limiting. Hence a study of the seasonal variation of nutrients in all possible localities could provide information on the primary productivity as well.

V. REGIONAL VARIATION IN PRIMARY PRODUCTIVITY

PRODUCTIVITY OF THE INSHORE AREAS

As the inshore areas of the Indian Seas sustain the bulk of the present yield the study of productivity was initiated in the inshore regions of Mandapam and then was extended to the west coast.

Table 6 gives the areas over the continental shelf for the different regions.

Table 6

Continental shelf areas of India

Region		Estimated area in hectares (thousands)	
		50 m	50-200 m
West coast			
Gujarat	..	6481	9937
Maharashtra	..	2551	10475
Goa	..	285	998
Mysore	..	794	2547
Kerala	..	1257	3594
West coast of Madras	..	84	780
		11452	28331

Table 6 (Contd.)

Region	Estimated area in hectares (thousands)	
	50 m	50-200 m
East coast		
East coast of Madras ..	2241	3362
Andhra ..	1161	3104
Orissa ..	1707	2363
West Bengal ..	995	2286
Laccadives, Andaman & Nicobar ..	6104	11115
Grand total	17556	39446

Out of the 307 million hectares of shallow water areas in the Indian ocean 57 million hectares are contiguous to the coastline of India. Though there is considerable variation in the magnitude of organic production, some of the most productive regions are found on the continental shelf.

In the Gulf of Mannar off Mandapam there are two peaks of production – one in April-May and another in October. In one shallow station near the Central Marine Fisheries Research Institute the mean monthly values for the surface waters were found to range 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 of study the values ranged from 124 mg C/m^3/day in July to 388 mg C/m^3/day in April with an average of 202 mg C/m^3/day (Prasad & Nair, 1963). The average annual production for six stations in the neighbourhood was 74 gc/m^3. For the near shore regions where the euphotic zone is only 6 m deep due to turbid conditions column production would amount to a fairly high value of 1.2-1.5 gC/m^2/day and an annual gross production of *ca* 450 gC/m^2. But just outside the zone where turbidity is not high enough to affect light penetration the euphotic zone extends from 15-40 m depending on the depth and distance from the shore. In such regions a daily production of 3-5 gC/m^2 are often met with. Table 7 gives the C^{14} assimilation values for a station off Tuticorin.

Table 7

C^{14} assimilation values off Tuticorin

Period	Depth	Production	
		mg C/m^3/day	gC/m^2/day
August	0	237	
	10	253	
	20	51	
	30	34	
	45	3.4	
			4.6*

* correction for standardization would raise the value by a factor 1.47.

Such high rates of production are characteristic of many shallow tropical areas because of the constant replenishment of nutrients from the bottom. An average rate of 3.0 gC/m^2/day with an annual gross production of 1000 gC/m^2 in the shallow region of Gulf of Mannar and Palk Bay makes it one of the most productive regions of the world. Studies conducted in the Palk Bay revealed that the rates of production are invariably very high (table 8). The averaging of all observations in the shallow regions give a value of 2.24 gC/m^2/day. During the period of phytoplankton bloom the surface production reached an exceptionally high value of 2340 gC/m^3/day. Production rates fell rapidly within 5 metres but there were appreciable production even at 10 metres. The column production varied from *ca* 1.0 gC/m^2/day to>6.0 gC/m^2/day and once even attained the highest figure of 8.68 gC/m^2/day.

In the inshore areas on the south west coast values over 2.0 gC/m^2/day are obtained within 50m depth during upwelling. Over the Wadge Bank at a station 38m deep, the production rate was 2.09 gC/m^2/day. Just below the surface the rate per unit volume was 12 mg/m^3/hour, suggesting a constant replenishment of nutrients. By using artificial light of 30klux rates as high as 52 mgC/m^3/hr have also been obtained with surface water during the upwelling period for a station south of Mangalore. Radhakrinshna (1969) observed in the shelf waters off Alleppey during the post-monsoon period values ranging from 0.38 gC/m^2/day to 1-11 gC/m^2/day with an average of 0.81 gC/m^2/day. He also found that carbon assimilation is highest at 50% optical depth. The surface values

Table 8
C^{14} Experiments in Palk Bay

Date	Place	Depth in m	Production mgC/m^3/day	gC/m^2/day
13-3-61	Mandapam	0	36.5	
		5	40.5	
		10	53.3	0.40
12-6-61	Mandapam	0	638.0	
		5	489.0	
		10	143.0	4.37
26-6-62	Mandapam	0	1061.5	
		10	153.2	6.04
4-7-62	Mandapam	0	2341.9	
		5	545.0	
		10	52.5	8.68
9-7-62	Mandapam	0	1375.2	
		5	53.3	
		10	37.5	3.77
11-7-62	Thangachimadam	0	774.3	
		6	147.2	
		12	8.9	3.20
18-7-62	Uchippuli	0	543.2	
		6	250.9	
		12	38.7	3.22
20-2-63	$9^0$24´N, $79^0$13´E	0	20.4	
		5	10.2	
		10	1.8	0.10
21-2-63	$9^0$44´N, $79^0$16´E	0	42.2	
		5	12.4	
		10	2.6	0.17
11-6-63	Mandapam	0	129.1	
		4	135.2	
		8	104.1	
		10	4.9	1.07
17-6-63	Mandapam	0	203.2	
		4	320.4	
		8	149.8	
		10	62.4	2.21
26-8-64	Mandapam	0	288.5	
		4	165.1	
		8	78.9	1.40
26-8-64	Mandapam	0	341.9	
		8	77.7	1.68
2-9-64	Mandapam	0	156.9	
		8	119.9	1.11
2-9-64	Mandapam	0	144.8	
		8	112.3	1.03
16-9-64	Mandapam	0	166.0	
		8	88.7	1.02
9-10-64	Mandapam	0	170.0	
		5	155.3	
		10	37.9	1.30
13-10-64	Mandapam	0	157.0	
		3.5	106.6	
		7	52.4	0.74

ranged from 24.12 to 170.75 mgC/day and in all except one of the 13 stations observed, the production rate was the highest at 50% light depth. Here it ranged from 40.95 to 196.62 mgC/day. At 25% light depth the rate averaged 56.97 mg/day. At 10% depth the range was 7.1 to 26.0 mgC/day and at 1% depth the values ranged from 0.02 to 5.98 mg/day. Dark fixation also was found to be very high at 10% light depth and below.

The highest value of 4.55 gC/m^2/day for the west coast was observed at a station on the Wadge bank in September. The annual rate of gross production was 434 gC/m^2 on the shelf within 50m depth. Thus inshore areas on the whole are very highly productive.

PRODUCTIVITY OF THE ARABIAN SEA

Fairly regular data are available on the production of organic matter for the Laccadive Sea and the coastal region between Cape Comorin and Karwar. Table 9 A gives the organic production rates for some stations within 50metre depth on the continental shelf of India, table 9B for regions outside and table 10 gives the available values for the shelf regions of the rest of Arabian Sea.

Table 9 A

Daily primary organic production expressed as grams carbon fixed beneath a square metre sea surface with station position etc.

Date	Position		Depth in metres	Production gC/m^2/day
	Latitude N	Longitude E		
5-6-65	$8^0$00′	$77^0$20′	38	2.09
15-12-65	$13^0$26′	$75^0$10′	40	0.95
16-12-65	Karwar Bay		7	1.39
3-2-66	$9^0$40′	$76^0$00′	40	0.18
6-9-66	$9^0$00′	$76^0$28′	25	1.24
7-8-67	$14^0$08′	$74^0$18′	30	0.61
6-9-67	$9^0$52′	$76^0$10′	18	2.37
7-9-67	$9^0$20′	$76^0$51′	50	1.18
”	$8^0$42′	$76^0$35′	35	1.26
9-9-67	$7^0$45′	$77^0$19′	50	0.48
”	$7^0$45′	$78^0$00′	47	1.43
20-7-68	$8^0$53′	$76^0$21′	50	1.12
21-7-68	$10^0$29′	$75^0$51′	37	0.89
22-7-68	$11^0$19′	$75^0$36′	28	1.34
24-7-68	$12^0$08′	$74^0$58′	37	2.45

Table 9 B
Daily primary organic production expressed as grams carbon fixed beneath a square metre of sea surface with station position etc.

Date	Position		Depth in metres	Production $gC/m^2/day$
	Latitude N	Longitude E		
4-6-65	$7^0 30'$	$76^0 00'$	1500	0.33
6-6-65	$8^0 50'$	$75^0 20'$	1200	0.03
7-6-65	$9^0 30'$	$75^0 10'$	2000	0.13
12-10-65	$9^0 50'$	$75^0 26'$	2000	0.11
13-10-65	$9^0 20'$	$75^0 39'$	4000	0.16
14-10-65	$8^0 44'$	$75^0 38'$	350	0.05
15-10-65	$7^0 53'$	$77^0 04'$	550	0.53
16-10-65	$8^0 15'$	$75^0 47'$	1200	0.06
11-11-65	$7^0 56'$	$76^0 55'$	70	0.07
11-11-65	$7^0 52'$	$76^0 38'$	900	0.22
12-11-65	$8^0 32'$	$76^0 00'$	200	0.13
12-11-65	$8^0 32'$	$76^0 21'$	300	0.01
13-11-65	$8^0 43'$	$75^0 26'$	800	0.13
15-11-65	-	-	200	0.50
24-11-65	$11^0 26'$	$74^0 51'$	82	0.11
25-11-65	$12^0 20'$	$74^0 40'$	58	0.05
25-11-65	$12^0 40'$	$74^0 15'$	86	0.27
27-11-65	$13^0 30'$	$73^0 00'$	1600	0.21
27-11-65	$13^0 30'$	$73^0 30'$	180	0.10
28-11-65	$12^0 20'$	$74^0 21'$	180	0.14
29-11-65	$11^0 15'$	$74^0 34'$	1200	0.04
14-12-65	$11^0 10'$	$75^0 10'$	60	0.57
19-12-65	$12^0 30'$	$74^0 16'$	180	0.04
6-1-66	$14^0 09'$	$73^0 20'$	160	0.25
7-1-66	$13^0 35'$	$72^0 55'$	1900	0.35
7-1-66	$13^0 06'$	$73^0 33'$	1800	0.28
8-1-66	$12^0 27'$	$74^0 20'$	120	0.25
21-4-66	$11^0 15'$	$74^0 49'$	260	0.45
22-4-66	$11^0 40'$	$76^0 08'$	1400	0.05
5-2-66	$7^0 50'$	$77^0 11'$	300	0.13
7-2-66	$9^0 30'$	$75^0 35'$	1000	0.07
8-2-66	$9^0 55'$	$75^0 09'$	2000	0.39
26-5-66	$12^0 50'$	$74^0 05'$	180	0.13
7-6-66	$8^0 12'$	$76^0 44'$	80	0.57
8-6-66	$8^0 46'$	$76^0 10'$	150	0.38
25-6-66	$13^0 30'$	$73^0 34'$	120	0.29
26-6-66	$11^0 56'$	$74^0 11'$	1700	0.22
7-9-66	$8^0 00'$	$77^0 11'$	60	0.55
7-9-66	$8^0 00'$	$76^0 58'$	90	0.55
8-11-66	$16^0 30'$	$73^0 40'$	110	0.11
8-11-66	$16^0 29'$	$71^0 42'$	300	0.12
6-12-66	$11^0 15'$	$74^0 55'$	120	0.09
9-3-67	$9^0 21'$	$75^0 52'$	188	0.05
18-4-67	$10^0 27'$	$72^0 41'$	1600	0.12
20-4-67	$10^0 43'$	$74^0 26'$	2160	0.21

Table 9B (Contd.)

Date	Position Latitude N	Position Longitude E	Depth in metres	Production $gC/m^2/day$
8-6-67	$10^0 28'$	$72^0 42'$	1900	0.06
9-6-67	$11^0 23'$	$72^0 46'$	1900	0.04
6-8-67	$12^0 44'$	$74^0 28'$	56	0.18
11-8-67	$11^0 16'$	$73^0 50'$	2100	0.05
8-9-67	$8^0 17'$	$75^0 44'$	1400	0.40
9-9-67	$7^0 45'$	$76^0 43'$	183	0.42
10-9-67	$7^0 27'$	$77^0 40'$	117	0.95
10-9-67	$7^0 32'$	$76^0 41'$	850	0.95

Table 10

Organic production values on the continental shelf areas in the Indian Ocean*

Latitude	Longitude	Depth in metres	Production $gC/m^2/day$
$29^0 32'$S	$31^0 18'$E	47	1.85
$29^0 26'$S	$31^0 33'$E	68	0.01
$25^0 10'$S	$33^0 15'$E	60	2.17
$20^0 42'$S	$35^0 50'$E	80	3.18
$20^0 14'$S	$35^0 16'$E	20	0.89
$19^0 10'$S	$36^0 19'$E	27	0.50
$16^0 46'$S	$43^0 45'$E	60	0.89
$02^0 56'$S	$40^0 23'$E	31	0.95
$29^0 11'$S	$31^0 37'$E	18.7	0.40
$23^0 20'$S	$43^0 36'$E	49.4	1.44
$24^0 42'$S	$35^0 23'$E	190	0.69
$24^0 48'$S	$34^0 59'$E	45.7	1.44
$26^0 01'$S	$33^0 04'$E	112	3.05
$33^0 13'$S	$42^0 53'$E	22	0.22
$29^0 29'$S	$31^0 44'$E	89	1.37
$29^0 18'$S	$31^0 33'$E	49	3.14
$07^0 41'$N	$97^0 59'$E	155	0.14
$08^0 29'$	$97^0 29'$E	60	0.13
$09^0 13'$N	$97^0 51'$E	64	0.11
$09^0 54'$N	$97^0 42'$E	73	0.23
$10^0 37'$N	$97^0 34'$E	94	0.27
$11^0 49'$N	$92^0 53'$E	87	0.01
$11^0 23'$N	$93^0 31'$E	80	0.36
$12^0 52'$N	$97^0 40'$E	64	0.17
$13^0 28'$N	$97^0 19'$E	72	0.14
$14^0 07$IN	$97^0 05'$E	62	0.11
$14^0 42'$N	$96^0 47'$E	76	0.17

Table 10 (Contd.)

Latitude	Longitude	Depth in metres	Production gC/m²/day	
15°20´N	96°24´E	18	2.89	
15°04´N	95°51´E	43	0.07	
15°08´N	94°54´E	29	0.25	
15°08´N	94°04´E	53	0.25	
19°41´N	93°08´E	38	2.16	
19°32´N	92°52´E	55	0.24	
20°35´N	87°51´E	80	0.83	
14°08´N	74°18´E	30	0.61	
09°52´N	76°10´E	18	2.37	
09°20´N	76°51´E	50	1.18	} 172
”	”	”	2.26	
08°42´N	76°35´E	35	1.26	
07°45´N	76°43´E	183	0.42	
07°45´N	77°19´E	50	0.48	
07°45´N	78°00´E	47	1.43	
07°27´N	77°40´E	117	0.95	
08°53´N	76°21´E	50	1.12	
10°29´N	75°51´E	37	0.89	
11°19´N	75°36´E	28	1.34	
12°08´N	74°58´E	37	2.45	

* ANTON BRUUN Cruise Reports, W. H. O. I.

Table 11

Regionwise productivity on the west coast

States	Up to 50 m			50 to 200 m			> 200 m		
	No. of Stns.	Total	Av.	No. of Stns.	Total	Av.	No. of Stns.	Total	Av.
Madras (West coast)	3	4.00	1.33	4	1.49	0.37	6	1.08	0.18
				1	4.55	4.55			
Kerala	10	12.17	1.22	13	3.20	0.25	22	3.80	0.17
Mysore	6	6.50	1.08	4	0.77	0.19	3	0.84	0.28
Maharashtra	-	-	-	2	0.23	0.12	-	-	-
	19	22.67	1.19	24	5.69	0.43	31	5.72	0.18

Table 11 gives the regionwise productivity for the various depth zones on the west coast. It may be seen that average for all the observations within 50 metres depth comes to 1.19 gC/m²/day, which amounts to

annual gross production of 434 gC/m^2. Assuming that 40% of this is being utilised for respiration the net production would amount to 260 gC/m^2/year. For the zone between 50 m depth and the edge of the continental shelf the average rate is 0.43 gC/m^2/day which is moderately high. The annual gross production of carbon would amount to 157 gC/m^2/year and the net production of gC/m^2/year. For the shelf region on the west coast the net production has been estimated at 46 x 10^6 tonnes per year, which is about 3 times that of total net production on the shelf region of the east coast.

Outside the shelf the level of organic production falls to <0.2 gc/m^2/day(Table 9B). But as this rate persists throughout the year an annual net productiuon of about 50 gC/m^2 can be expected. Higher rates of production are found in the vicinity of Laccadive and Minicoy Islands. The Arabian sea when considered on the whole is a region of great contrast as was observed during the International Indian Ocean Expedition (Ryther et al., 1966). High productivity was observed in the northern and western Arabian Sea. Oceanic regions recorded 1.8 gC/m^2/day (Ryther and menzel, 1965). Exceptionally high values were found off the coast of Saudi Arabia and West Pakistan. Twentythree measurements made in that region by Ryther *et al*. (*l.c*) show values in excess of 1.0 gC/m^2/day with a maximum 6.4 gC/m^2/day. These authors remarks that the Somali coast, though has been assigned only moderately high rates of production due to lack of measurements, higher levels of production are expected along the west and perhaps some distance off shore atleast during the southwest monsoon when there is strong coastal upwelling. A large area of low productivity with rates of < 0.26 gC/m^2/day was observed by them between 60^o and 80^o E. But where there is deep water ascent the values of primary production increase and the daily rate is between 50 and 120 mgC/m^3/day (Kabanova, 1961).

The reason for the very high productivity in certain regions of Arabian Sea lies in the presence of unusually high levels of inorganic nutrients at shallow depths often within or close proximity to the euphotic . When these nutrients are brought to the surface a high level of primary production could be substained. The monsoon shift provides the required energy for the vertical mixing which brings appreciable quantities of nutrients to the surface layers. Rao (personal communiction)

has observed high concentrations of phosphates (3.73 ug. at/1) during May-June in the eastern Arabian Sea between 0-and 200 metres. In the western Arabian Sea also high concentrations of phosphate (>2.0 ug. at/ 1) have been observed at depths of 100-500 metres (Ryther *et al., I.c.*). The rich water from the intermediate depths when brought up to the surface support a heavy growth of plankton organisms which spread seaward with the surface currents. The migration of these organisms or the animals that feed on them can thus sustain large stocks of pelagic fishes in the open ocean where the apparent organic production is of a lower order. Hence large shoals of pelagic fishes could sustain in the open parts of the Arabian Sea in view of the high productivity in certain regions.

Large mass moralities of fish reported in the Arabian Sea are considered as an adverse effect of high productivity. As a result of the death and decay of large quantity of organic matter the subsurface water becomes further enriched and depleted of oxygen. The level of oxygen and nutrients which are inversely related depend on the speed of circulation and when the circulation is slow the subsurface waters tend to become anoxic. When these waters are transported to the surface mass mortalities occur (Ryther *et al*., 1966).

PRODUCTIVITY OF THE BAY OF BENGAL

For the Bay of Bengal area much data on the productivity are not available. According to Steemann Nielsen and Jensen (1957) 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. Besides, through the supply of fresh water by a number of river systems the salinity is relatively low.

Lafond and Lafond (1968) have investigated the water motion during the 1st cruise of R/V. ANTON BRUUN. According to these authors 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 as 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 the euphotic 45-66 metres at the western region and 84-99 metres in the western region indicating low productivity. The lower transparency in the western part is presumably due to the organic and inorganic material oxyed by the rivers which decrease the rate of photosynthesis per surface area.

The production rate was on the average 0.19 gC/m^2/day in the deeper part while the shelf stations were all characterised by a high rate of production with an average of 0.63 gC/m^2/day (Table 12).

Table 12
Rate of production in the Bay of Bengal as reported by
GALATHEA and ANTON BRUUN *

Date	Latitude	Longitude	Depth (m)	Production gC/m^2/day
23-4-51	$14^0 20´N$	$82^0 00´E$	3240	0.12
24-4-51	$17^0 10´N$	$84^0 38´E$	2860	0.25
4-5-51	$13^0 58´N$	$91^0 03´E$	3000	0.24
2-5-51	$19^0 53´N$	$89^0 05´E$	1400	0.16
3-5-51	$10^0 32´N$	$90^0 59´E$	850	0.31
26-4-51	$20^0 37´N$	$87^0 33´E$	62	0.60
27-3-63	$11^0 49´N$	$92^0 53´E$	87	0.01
28-3-63	$11^0 23´N$	$93^0 31´E$	80	0.36
1-4-63	$15^0 08´N$	$94^0 54´E$	53	0.25
“	$15^0 08´N$	$94^0 04´E$	53	0.25
5-4-63	$19^0 41´N$	$93^0 08´E$	38	2.16
“	$19^0 32´N$	$92^0 52´E$	55	0.24
22-4-63	$20^0 35´N$	$87^0 51´E$	80	0.83
26-4-63	$17^0 41´N$	$83^0 19´E$	65	1.53
“	$17^0 35´N$	$83^0 25´E$	67	0.11

* After Steemann Nielsen and Jensen, 1957 and Woods Hole Oceanographic Institution Data Sheet, 1964.

This average value is moderately high but is only about one-half of the productivity of the west coast within 50 metre depth but slightly more of the average value for the region outside. The total net production of the shelf amounts to $15x\ 10^6$ tonnes.

PRODUCTIVITY OF THE INDIAN OCEAN IN GENERAL

The measurements made by GALATHEA showed that all stations at middle latitudes in the western part outside the continental shelf were characterised by a production rate between 0.1 and 0.2 gC/m^2/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 gC/m^2/day . On the Agulhas Bank water from the lower boundary of the photosynthetic zone showed three and a half times the rate of production form that of the surface under constant illumination, indicative of a distinct ascent of nutrient-rich water to the photosynthetic layer (Steemann Nielsen and Hensen, 1957). In the south equatorial current a relatively high production rate. 0.22.0.23 gC/m^2/day, was found. The coast of Ceylon has a high production rate.Very high values were observed south-east of Java. Summarizing all the GALATHEA measurements in the equatorial current systems of Indian Ocean, Steemann Nielsen and Jensen (1957) concluded that the rate of production is moderately high in the whole region of the equatorial current system and in restricted areas very high rates of production are found.

Kabanova (1961) reported that primary production in the open part of the ocean was low and did not exceed 0.01-0.03 gC/m^2/day. An increase in the value of primary production was observed in coastal waters in-and in the zones of ascent of deep water. In the Banda Sea the production reached 0.236 gC/m^2/ day, while on the Australian shelf the value increased up to 0.45 gC/m^2/day. In the African-Madagascar region it was 0.072 gC/m^2/day. The Arabian Sea water was characterized by an especially high productivity connected with the presence of regions of deep water ascent.

For the western Indian Ocean, Ryther *et al*. (1966) observed two large areas of low productivity, one to the north extending from 80^0 to nearly 60^0 E Long., and from the Indian continent to about 5^0 S Lat., and another from 10^0 to about 40^0 S Lat. and from 80^0 Long. nearly to the African coasts out of Madagascar. ANTON BRUUN measurements do not include any from near the coast. However, Nair *et al*. (1968) found that the level of organic production is high towards the coast and becomes less seaward.

Ryther *et al.* (1966) noticed moderately productive waters (0.26-gCm^2/day) between 5^0 and 10^0 S Lat. Pockets of high productivity (1.00 gC/m^2/day) were noted along the south-east coast of Durban, Marques and Beira. On the seaward side of Agulhas Current relatively low levels of productivity were encountered.

North of the equator and into the Arabian Sea the level of organic production increases to the north and west, reaching exceptionally high values of the coasts of Saudi Arabia and West Pakistan. Based on ANTON BRUUN measurements, Ryther, *et al*. (1966) calculated that for western Indian Ocean, where the ANTON BRUUN survey was carried out for an area of 23 x 10^6 sq km (about one-third of the Indian ocean as conventionally mentioned). The annual productivity is 3 x 10^9 tonnes of carbon which an average of 0.35 gC/m^2/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 per cent of the area surveyed.

Mitchell-Innes (1967)found for the region off South Africa, between attitudes 26^o and 47^o S, values ranging from 0.03 to 1.08 gC/m^2/day. Productivity was observed (0.5 gC/m^2/day) in Deloga Bay and off port Elizabeth. Burchall (1968 a, b) observed values ranging from 0.02 0.94 gC/m^2/day in the Agulhas Current region off Natal. Areas of high production were located in the vicinity of the continental shelf and also at the eastern boundary of the Agulhas current. The average net production for the western half of the Indian Ocean (0.24 gC/m^2/day) is a little higher than the eastern half (0.19 gC/m^2/day). Over the shelf on annual average is more than double that of outside.

Prasad *et al*. (1970) have estimated that the annual net production for 51 million sq km of the Indian ocean is about 3.9 x 10^9 tonnes of carbon which is about one-fifth of the world ocanic production. Of this 7.3 x 10^9 tonnes of carbon is for the western region comprising 29 million Sq.km. and 1.6 x 10^9 tonnes for the eastern region with 22 million sq km, the dividing line being taken as 80^o E long. The continental shelf area is only about 6% of the total area accounts for 560 x 10^6 tonnes of the total net production. Of this, the contribution from the Indian coastal region is 61 million tonnes which is roughly 1 tonnes per year or 100 gm per square metre.

But it may be observed that the averages are misleading as there it marked difference in the general level of production between the west coast and east coast as well as the shallow areas of Gulf of Mannar, Palk Bay and Wadge Bank with the other areas. It can be concluded that the organic production in the Indian Seas is moderately high with pockets of very high productivity in localised areas (Fig. 4; partly after Ryther *et al*., 1966 and partly after Prasad *et al*., 1970).

PRODUCTIVITY IN ESTUARIES

Qasim *et al*. (1969) studied organic production in Vembanad estuary. It was observed by these authors that there is a seasonal cycle in production. High values are recorded from April to August and low values from September to March. The gross production fell within a range of 272-293 gC/m^2/year with an average of 281 gC/m^2/year. Similarly the net production for days ranged from 184 to 202 gC/m^2/year with an average 195 of gC/m^2/year and the average for days and nights is approximately 124 gC/m^2/year.

PRODUCTIVITY OF CORAL REEFS

Coral reefs abound in the Laccadives and Andaman Seas on the south east coast of India. With regard to the rate of organic production coral reefs excel that of any other marine environment (See tables 13 & 14). The symbiotic zooxanthellae and the boring algae on the coral heads contribute to the major share of the high productivity over the coral reefs. However a good part of this organic matter is used up for the metabolic requirements of the reef organisms. Based on Photosynthesis/ Respiration ratios the reefs are classified as autotrophic (P/R=> 1) or heterotrophic (P/R=<1).

Table 13

Annual primary productivity (gross) in certain marine environments are grams carbon per square meter sea surface

Locality	Production $gC/m^2/year$	Reference
Barents Sea	170-330	Kreps & Verjbinskaya, 1932
English Channel	60-98	Cooper, 1933
Georges Bank	309	Riley, Stommel & Bumpus, 1949
North Sea	57-82	Steele, 1956
Long Island Sound	470	Riley, 1956
Off Hawaii (open ocean)	21	Doty & Oguri, 1956
" (inshore)	123	-do-
Turtle grass bed (Florida)	4650	Odum, 1956
Hawaiian coral reef	2900	Kohn & Helfrich, 1957
Shelf water off New York		
(shallow coastal region)	160	Ryther & Yentsch, 1958
(Continental slope)	100	
North Central Sargasso Sea	78	-do-
Gulf of Mannar		
(Inshore within 10 m depth)	745	Prasad & Nair, 1963
Temperature oceans	100-150	Strickland, 1965
Equator	110-146	-do-
Barren tropical oceans	50	-do-
Cochin back water	281	Qasim *et al*., 1968 (in press)
West coast of India		
(within 50 m depth)	434	Nair *et al*., 1968
East coast		
(continental shelf)	230	-do-
Kavartti lagoon		
(Laccadives)	4715	Qasim et al. CMS
Kavaratti reef		
(Laccadives)	2250	-do-
Minicoy reef	3000	Pillai & Nair (1969)
Mandapam reef	2500	-do-
Andaman reef		
(Port Blair)	1200	-do-

Table 14

Gross and net organic production of various natural and cultivated systems in grams dry weight produced per square meter per day.*

	Gross	Net
A. Theoretical potential		
Average radiation (200-400 g cal/cm^2/day)	23-32	8-19
Maximum radiation (750 g c l/cm^2/day)	38	27
B. Mass cutdoor Chlorella culture		
Mean		12.4
Maximum		28.0
C. Land (Maxima for entire growing seasons)		
Sugar		18.4
Rice		9.1
Wheat		4.6
Spartina marsh		9.0
Pine forest (best growing years)		6.0
Tall prairie		3.0
Short prairie		0.5
Desert		0.2
D. Marine (maxima for single days)		
Coral reef	24	(9.6)
Turtle grass flat	20.5	(11.3)
Polluted estuary	11.0	(8.0)
Grand Banks (April)	10.8	(6.5)
Walvis Bay	7.6	
Continental Shelf (May)	6.1	(3.7)
Sargasso Sea (April)	4.0	(2.8)
E. Marine (annual average)		
Long Island Sound	2.1	0.9
Continental Shelf	0.74	(0.40)
Sargasso Sea	0.74	(0.35)

* from Ryther 1959

The classical methods using light and dark bottle or C^{14} are applicable in the study of reef productivity. The diurnal changes of oxygen at two stations in the direction of flow along with the oxygen diffusion rates are used for computing the productivity of reefs (1956). The direction and speed of flow of water are determined by flourescein dye.

Using this technique the organic productivity of some reefs in Mandapam, Minicoy, Andamans (Nair & Pillai 1969) and in laccadives (Qasim *et.aI.*MS) was studied. It was found that Mandapam and Minicoy reefs are autotrophic with annual net production of 2500 gC/m^2 and 3000 gC/m^2 respectively. The reef near Port Blair was found to be nonautotrophic with a production of 1200 gC/$m^{2/}$/ year, which does not meet the respiratory requirements of the reef organisms. The relative difference in productivity of ambient waters and paucity of benthic algae on the Andaman reef seems to account for this difference. The Kavaratti lagoon in the Laccadives was found to have a gross production of 4715 gC/$m^{2/}$year of which 3482 gC/m^2 year is consumed and the reef has a production of 2250 gC/m^2 /year and consumption of 880 gC/$m^{2/}$year (Qasim *et. al.* MS). The reef communities on some Atolls thus produce more organic matter in a day than what they consume in 24 hours.

VI. PRIMARY PRODUCTION IN RELATION TO FISHERIES.

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 and 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 euphausids. These crustaceans and their larvae constitute the talk of the food of the other plankton animals including pelagic fish larvae and the plankton feeding fish. The most important plankton eating 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.

The food is converted by the fish partly into growth. The efficiency of conversion is higher in young fish and lower in old fish

as the growth is slower in the latter. The conversion factor is about 4.0 - 8.0 depending on the nutritional value of food.

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 (Cusing 1959).

Based on the data collected so far the gross organic production on the shelf within 50 metres over an are of 114, 520 square kilometres, where there is active fishing, as indicated earlier, has been estimated at 50×10^6 tonnes and the net production available to the environment would be 30×10^6 tonnes carbon. The present yield of fish from the west cost is 676,000 tonnes which comes mostly from this shallower inshore area. In terms of carbon it amounts to 0.2% which is only one half of the maximum sustainable yield. For the rest of the continental shelf area the net production amounts to 16×10^6 tonnes which should yield another 3.2 lakh tonnes even at the present rate of exploitation. So the minimum harvestable crop from the west coast seems to be 2 million tonnes.

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 for the transfer of carbon produced to higher trophic levels. A similar approach has been made for the inshore areas in the west coast (Table 16).

Table 16

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

Trophic level	Ecological efficiency factor					
	10%		15%		20%	
	Carbon	Total wt.	Carbon	Total wt.	Carbon	Total wt.
(0) Net primary production	$3x10^7$		$3x10^7$		$3x10^7$	
(1) Herbivores	$3x10^6$	$3x10^7$	$4.5x10^6$	$4.5x10^7$	$6x10^6$	$6x10^7$
(2) 1st stage carnivores	$3x10^5$	$3x10^6$	$6.8x10^5$	$6.8x10^6$	$12x10^5$	$12x10^6$
(3) 2nd stage carnivores	$3x10^4$	$3x10^5$	$10.2x10^4$	$10.2x10^5$	$24x10^4$	$24x10^5$
(4) 3rd stage carnivores	$3x10^3$	$3x10^4$	$15.3x10^3$	$15.3x10^4$	$48x10^3$	$48x10^4$

Since it is very difficult to assign a proper trophic level to the different catogeries of fishes as they may operate at more than one trophic level on the assumption of Shaeffer (*I.c.*) that the harvest is all taken at step, 3, the following will be the potential yield for this zone 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 more than double the potential yield at 10% level, we can conclude that 10% efficiency factor and harvesting at stage 3 is too low. At 15% efficiency factor the possible increase is 1.1 times and at 20% efficiency it is possible to increase 3.5 times. Recent studies indicate that ratios of production of total zooplankton to net production of phytoplankton which exceed 20% need not be considered usual – cf. Mullin, 1969). However, if it is assumed that half of the potential might 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 according to Schaeffer (*l.c*) the available potentials would be as follows:

Ecological Efficiency Factor	Total biomass of fish (tonnes)
10%	16,50,000
15%	39,10,000
20%	72,00,000

Taking into consideration the depletion of stock due to other predators and the economic inability to harvest some components which are diffusely distributed it can be assumed that half of the total biomass would be available for harvest. This will also amount to 2 million tonnes of fish.

For the east coast taking the average production rate of 0.63 gC/m^2/day the total net production over the shelf area would amount to 15 x 10^6 tonnes of carbon and the optimum yield of fish would be 6,00,000 tonnes. As the present yield is 2, 14, 600 tonnes the potential harvest on the east coast also would be about 3 time the present yield.

Thus considering the east and west coast together the potential resources over the entire shelf region would be atleast 2-3 million tonnes as the studies on primary production indicate.

Prasad *et. al.* (1970) have recently made quantitative assessment of the potential resources of the Indian ocean from primary production and zooplankton biomass in the light of exploratory fishing data available from various sources. The estimate of organic production for an area of 51 million square kilometres is 3.9x 10^9 tonnes. The estimate of the possible catch at the present level of world fishing is 11-12 tonnes. This figure has been arrived at by comparison of the yield ratio in the Indian Ocean with that of Atlantic and Pacific Oceans. However, the potential harvest derived from estimates of fish biomass based on carbon production and it subsequent transfer through various trophic levels, is about 39-40 million tonnes.

Table 15 gives the present yield as percentage of carbon productions in different regions and the probable potential increase based on the above ratio.

Table 15

Yield as percentage of carbon production and probable potential increase

Area	Yeild ratio as % C	Probable potential increase
Atlantic	0.040	-
Pacific	0.030	-
World Oceans (mean)	0.030	-
Indian Ocean	0.005	x6
Continental shelf (Indian Ocean)	0.035	x10
Gulf of Mannar	0.072	x5
West coast of India	0.225	x2
East coast of India	0.143	x3

VII. CONCLUSION

Studies on primary production in the seas around India indicate that the shallow areas of Gulf of Mannar and Palk Bay are extremely productive with an average rate of 2.0 gC/m^2/day during most of the year with the highest values of over 6.0 gC/m^2/day, which makes it comparable to other highly productive regions in the world. The inshore waters of the west coast have an average rate>1.0 gC/m^2/day with maximum production during the upwelling season.

The annual net production of the Indian ocean for an area of 51 million square kilometres has been estimated at 3.9×10^9 tonnes of catch which is approximately one-fifth to one-sixth of the world oceanic production. The continental shelf areas of the Indian Ocean alone which occupy about 307 million hectares produce 560×10^6 tonnes of carbon. Contiguous areas of the continental shelf of the Indian subcontinent comprising 57 million hectares produce 61×10^6 tonnes of carbon. The west coast of India with a wider continental shelf and more pronounced upwelling accounts for three-fourths and the east coast one-forth of entire net production which is reflected in the magnitude of the present yield as well. The potential harvest as derived from the yield ratio from carbon production is about 2-3 million tonnes of fish for both the coasts. The potential yield as deduced from productivity data for whole Indian Ocean at the present level of world fishing is 11 million tonnes. Thus primary productivity studies apart from giving an idea of the relative fertility of water masses, enable a quantitative assessment of the potential resources and provide valuable information on the possibilities of large scale fishing.

The results so far obtained have touched only the fringes of the problem. Much more work is required to understand the spatial and temporal variations in productivity parameters of the Indian seas. The shelf regions of the west and east coasts and the surrounding oceanic areas require elaborate study. The seas around Laccadive-Minicoy which are rich is tuna resources and Andaman-Nicobar area also require further investigation. Besides, work on the energy input and output at the various lavels, chlorophyll studies, photosynthetic rate and chlorophyll content

in different species of phytoplankton grown in cultures, relation between pigments and production etc., are required in the eludication of the various aspects of trophic-dynamic ecology of the marine communities.

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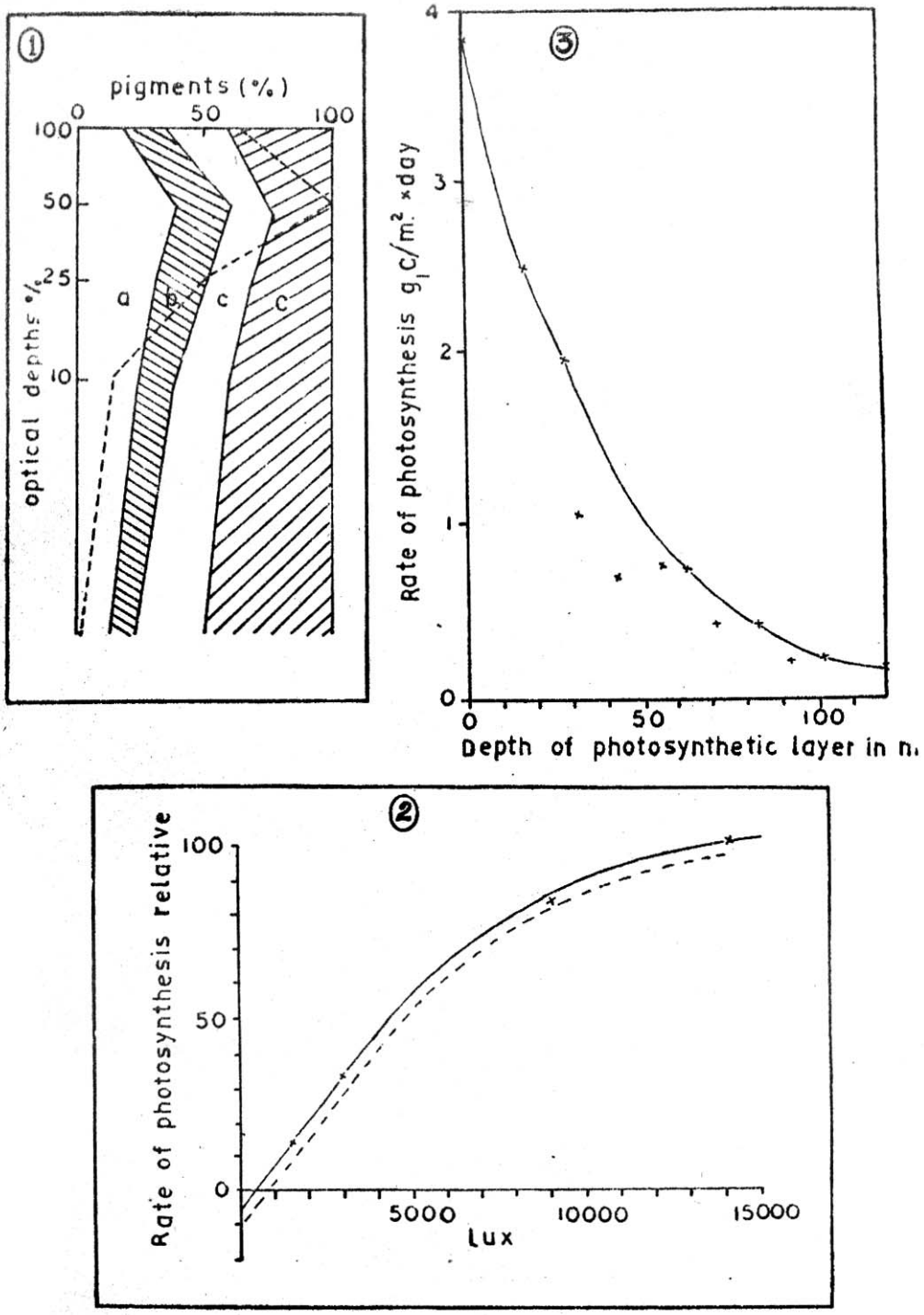

Figs. 1-3. 1. Optical depth-wise distribution of chlorophylls a, b, c, and carotenoids (C). Carotenoids represented as 10 MSPU, and optical depths on semi-logarithmic scale. Broken line: carbon assimilation (mg C/m³ / day) (after Radhakrishna, 1969).

2. Light intensity and rate of photosynthesis. Dashed line = net production. (After Steemann Nielsen & Hansen 1959).

3. Depth of photosynthetic layer and maximum rate of photosynthesis per m² surface. (After Steemann Nielsen & Jensen 1957).

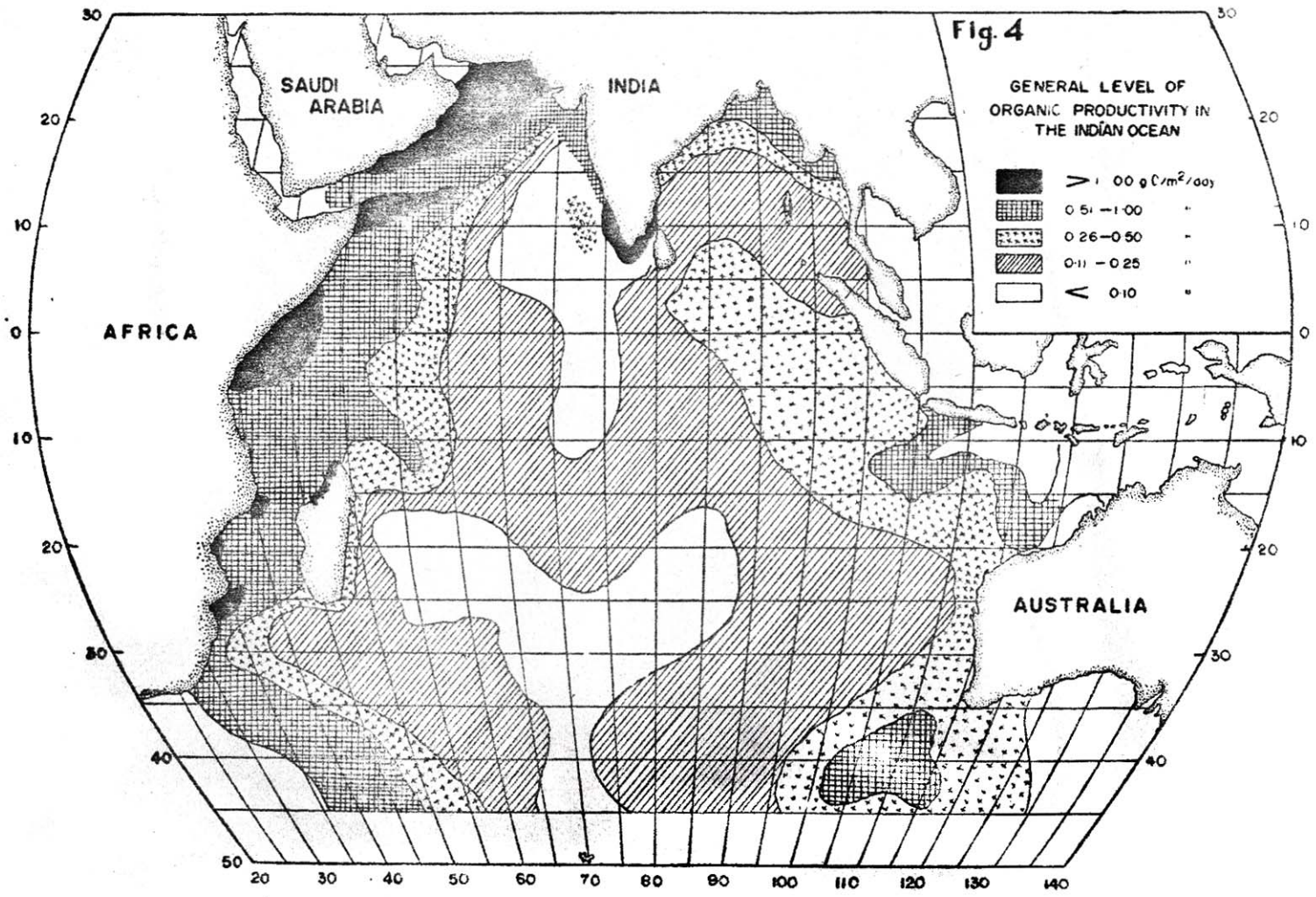

Fig. 4. Productivity chart for the Indian Ocean. (The Western Indian Ocean from Ryther *et al* 1966).

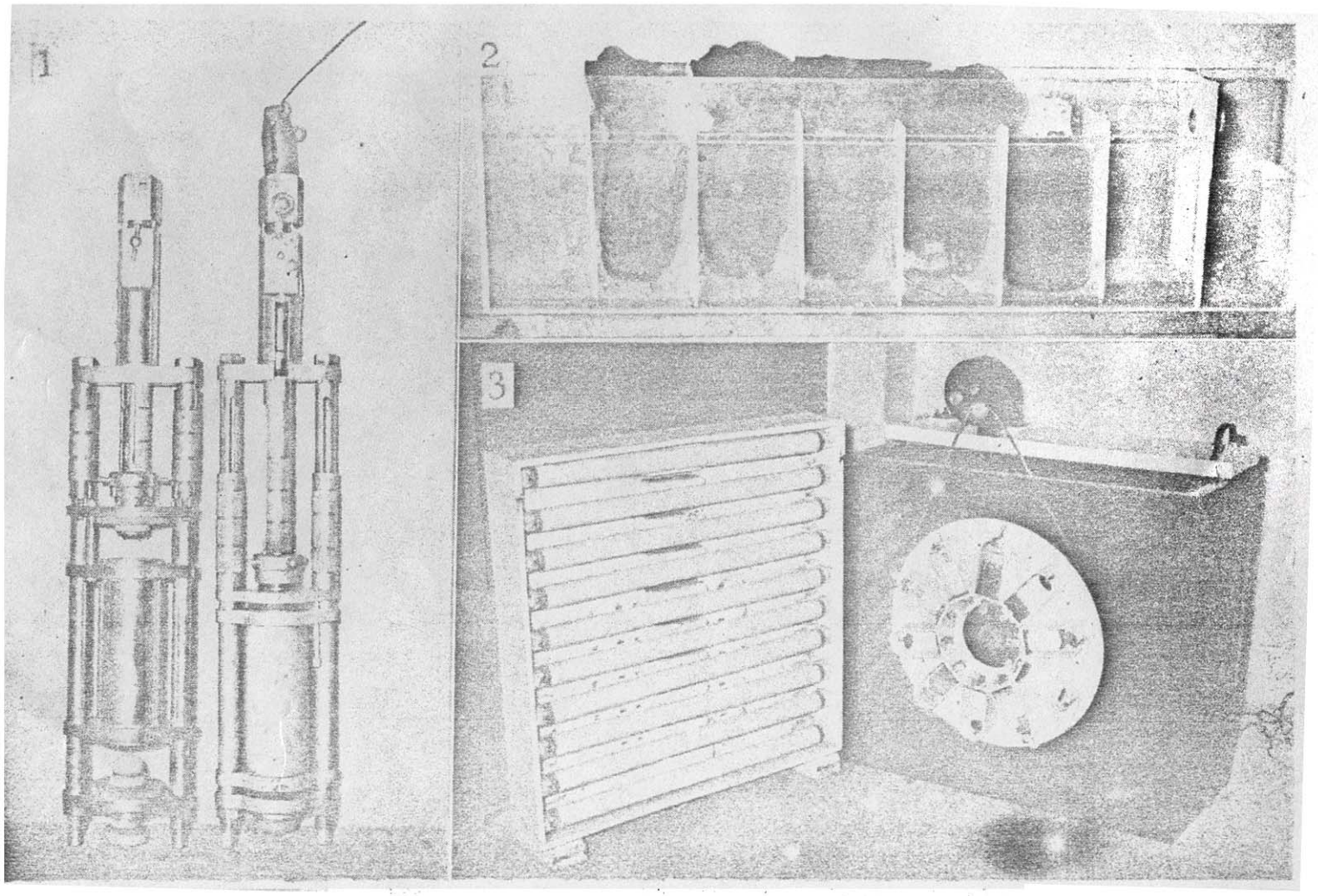

Plate I. 1. Insulated water bottle (open & closed).
2. Deck incubator with neutral density filters.
3. Rotary Incubator and light paner.

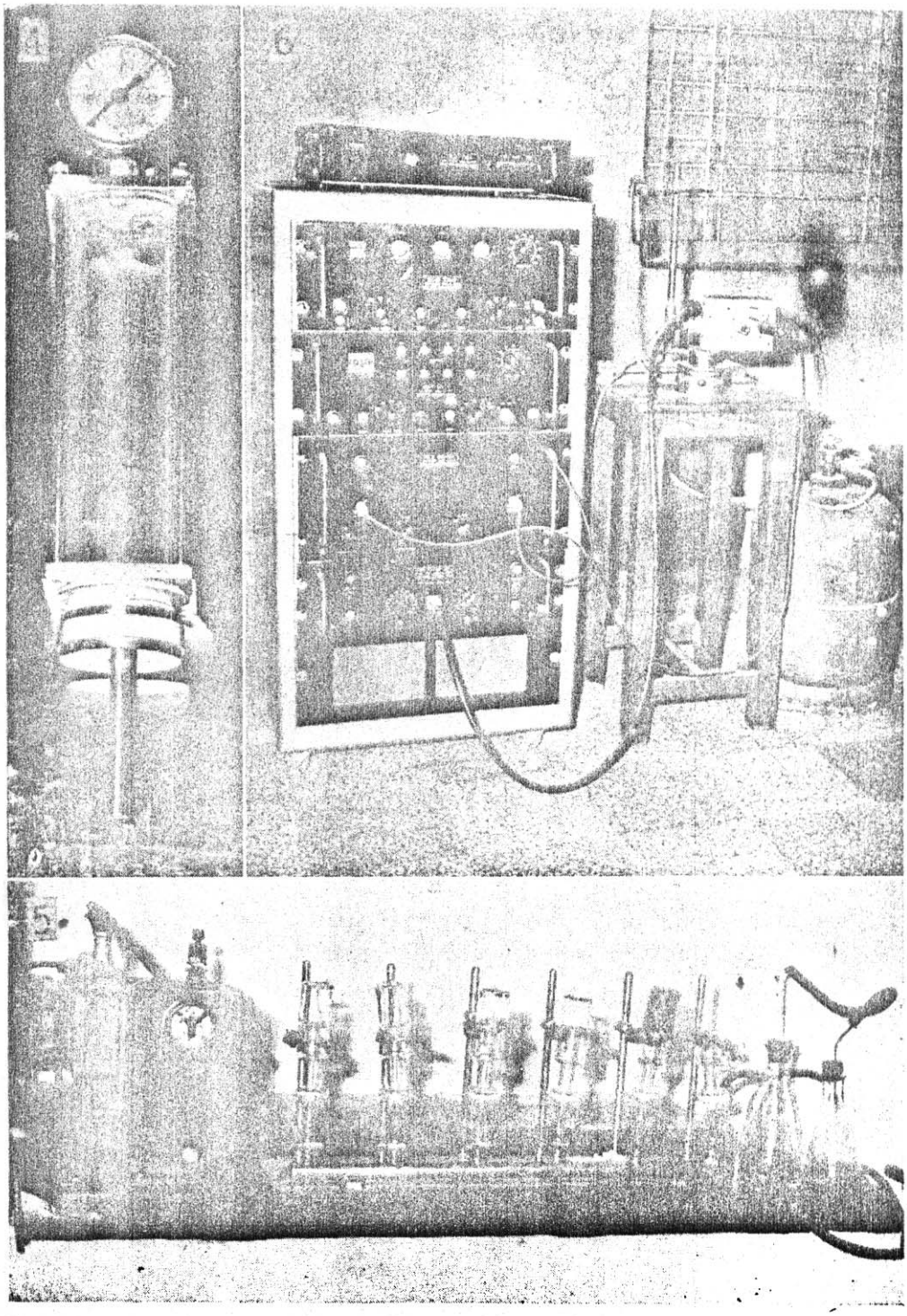

Plate II. **4. Field Filtering Unit.**

5. Manifold Filtering Unit.

6. Gas flow proportional counting system.

REFERENCES

Arthur. C.R. and F.H. Rigler. 1967. A possible source of error in the ^{14}C method of measuring primary productivity. *Limnol. Oceanogr*., **12(**1**):** 121-124.

Atkins,W.R.G. 1922 The hydrogen ion concentration of sea water and its biological relations. *J. Mar. biol. Assoc. U.K.*, **12**: 717-771.

Atkins, W.R.G. 1923. The phosphate content of fresh and salt waters in its relation to the growth of algal plankton. *Ibid*., **13**: 119-150.

Burchall, J. 1968. Primary production studies in the Agulhas Current region off Natal. *S. African Ass. Mar. Biol. Res., Oceanogr. Res. Inst., Investigational Rep*.,, **20**: 1-16.

Calvin, M., C. Heidelberger, J.C. Reid, B.M. Tolber and P.E. Yankwich. 1949. Isotopic Carbon.Techniques in its measurements and chemical manipulation. New York.

Cooper L.H.N. 1958. Consumption of nutrient salts in the English Channel as a means of measuring production. *Rapp. Proc.-Verb.Cons. Expl. Mer.,* **144:** 35-37.

Cushing D.H. 1958. The estimation of carbon in phytoplankton. *Ibid*., **144**: 82-83.

Cushing D.H. 1959. On the nature of production in the sea. *Fish. Invest. Ser. II***, 22:** 1-40.

Doty M.S. and M. Oguri. 1958. Selected features of the isotopic carbon primary productivity technique. *Rapp. Proc.-Verb. Cons. Expl. Mer*., **144:** 47-55.

Doty M.S. and M. Oguri. 1959. The Carbon-Fourteen technique for determining plankton productivity *Publ. Staz. Zool. Napoli*. **31**; suppl.: 70-94.

Dyson N., H.R. Jitts and B.D. Scott. 1965. Techniques for measuring oceanic primary production using radioactive carbon. CSIRO *Tech. Paper No.* **18: 1-12.**

Fedosov, M.V. 1958. Investgations of the chemical basis of productivity in sea basins. *Rapp. Proc.- Verb. Cons. Expl. Mer.,* **144:**61-64.

Fogg, G.E. 1958. Extra cellular products of phytoplankton and the estimation of primary production. *Ibid*., **144**: 56-60.

Fogg, G.E. 1963. The role of algae in organic production in aquatic environments. *Brit. Phyc. Bull.*, **2:** 195-205.

Fogg, G.E. 1969. Oxygen-Versus ^{14}C-methodology. In IBP Hanbook No.12 (Ed. Vollenweider). Blackwell, Oxford, 76-79.

Ggaarder, T. and H.H. Gran, 1927. Investigations of the production of plankton in the Olso Fjord. *Rapp. Proc.-Verb. Cons. Expl. Mer.,* **42**: 1-48.

Hall, H.M.W. 1949. Measurements to determine extinction coefficients in the North Sea and English channel. *J. Mar. biol. Assoc. U.K*., **28:** 509-527.

Harvey. H.W. 1934. Measurement of phytoplankton populations. *Ibid*., **19: 7**61.

Harvey. H.W. 1957. The chemistry and fertility of sea waters. Cambridge University Press. 2nd Edition.

Humphrey, G.F. 1966. The concentration of chorophylls *a* and *c* in the south-east Indian Ocean. *Austr. J. Mar. Freshw. Res.*, **17:** 135-145.

Jitts, H.R. and B.D. Scott. 1961. The determination of zero thickness activity in Geiger counting of C-14 solutions used in marine productivity studies. *Limnol. Oceanogr*., **6**: 116-123.

Kabanova, Ju.G. 1961. Primary production and nutrient salts content in the water of the Indian Ocean. *Okeanol.Issled*., No.4 72-75.

Kabanova, Ju.G. 1961. Primary production and nutrient salts content in the water of the Indian Ocean waters in October-April 1960-61. *Trud. Inst. Okeanol.,* **64**: 85-93.

Kohn, A.J. and P. Helfrich. 1957. Primary organic productivity of a Hawaiian coral reef. *Limnol. Oceanogr.,* **2**: 241-251.

Kreps, E. and N. Verbinskaya. 1930. Seasonal changes in the Barents Sea. *J. Conseil. Expl. Mer*., **5**: 329.

Krey, J. 1958. Chemical methods of estimating standing crop of phytoplankton. *Rapp. Proc.-Verb. Cons. Expl. Mer.,* **144**: 20-27.

LaFond, E.C. and K.G. LaFond. 1968. Studies of oceanic circulation in the Bay of Bengal. *Bull. Natn. Inst. Sci. India,* **No.38***:* 164-183.

McAllister, C.D. 1961. Observations on the variation of planktonic photosynthesis with light intensity using both the O_2 and C-14 methods. *Limnol. Oceanogr*., **6**(4): 483-484.

McGILL, D.A. and Lawson, Jr. 1966. The distribution of chlorophyll in the western India Ocean during the northeast monsoon period *Tech. Rep. WHOI*. No. 66-12.

Mitchell-Innes, B.A. 1967. Primary production studies in the south-west Indian Ocean 1961-1963. *S. African Ass. Mar. Biol. Res*., *Oceanogr*. *Res.Inst*., *Investigational Rep*., **20**: 1-16.

Mullin, M.M. 1969. Production of zooplankton. *Oceanogr. Mar. Biol. Ann. Rev*., **7**: 293-314. (H. Barnes, Ed.).

Nair, P.V.R. 1966. Standardization Carbon14 stock solution using scintillation and biological methods in primary production studies. *Proc. Atomic energy Establishment, Trombay, India*: 15-20. (Mimeo).

Nair, P.V.R. Sydney Samuel, K.J. Joseph and V.K. Balachandran. 1968. Primary production and potential fishery resources in the seas around India. *Proc. symposium on Living Resources in the Seas around India, Cochin.*(Abstracts).

Nair, P.V.R. and C.S. Gopinadha pillai. 1969. Primary productivity of some coral reefs in the Indian seas. *Proc. Symposium on Corals and Coral Reefs, Mandapam Camp, India.*

Odum, H.T. 1956. Primary production in flowing waters. *Limnol. Oceanogr*., **1**: 103-117.

Panikkar, N.K. 1967. Fishery resources of the Indian ocean. *Bull. natn. Inst. Sci. India,* **38**: 1-22.

Parsons, T.R. and J.D.H. Strickland. 1963. Discussion of spectrophotometric determination of marine plant pigments, with revised equations for ascertaining chlorophylls and carotenoids. *J. Mar. Res*., **21**: 155-163.

Prasad, R.R. and P.V.R. Nair, 1960. A preliminary account of primary production and its relation to fisheries of the inshore waters of the Gulf of Mannar. *Indian J. fish*., **7**(1): 165-168.

Prasad, R.R. and P.V.R. Nair. 1962. A comparison of values of organic production obtained from oxygen and C14 methods. *Proc. Indian Acad. Sci*., **56**B: 296-301.

Prasad, R.R. and P.V.R. Nair, 1963. Studies on organic production. I. Gulf of mannar. *J. Mar. biol. Ass. India*, **5**(1): 1-26.

Prasad, R.R., S.K. Banerjii and P.V.R. Nair., 1970. A quantitative assessment of the potential fishery resources of the Indian Ocean and adjoining seas. *Indian J. Anim. Sci*., **40**(1): 73-98.

Qusim, S.Z., P.M.A. Bhattathiri and S.A.H. Abidi. 1968. Solar radiation in a tropical estuary. *J. Exp. Mar. Biol. Ecol.,* **2**: 87-103

Qusim, S.Z., S. Wellershaus, P.M.A. Bhattathiri and S.A.H. Abidi. 1969. Organic production in a tropical estuary. *Proc. Indian Acad. Sci*., **69**(b): 51-94.

Qusim, S.Z., P.M.A. Bhattathiri and C.V.G. Reddy. 1970. Primary production of an atoll in the Laccadives. (In press)

Radhakrishna, K. 1969. Primary productivity studies in the shelf waters off Alleppey, south-west India, during the post-monsoon, 1967. *Mar. Biol.,* 4: 174-181.

Reddy, C.V.G. and V.N. Sankaranarayanan. 1968. Distribution of phosphates and silicates in the Central, Western, North Indian Ocean, relation to some hydrographical factors. *Bull. Natn. Inst. Sci.India*,No. 38: 103-122.

Reddy, C.V.G. and V.N. Sankaranarayanan. 1968. Distribution of nutrients in the shelf waters of the Arabian Sea along the west coast of India. *Ibid*., No. 38: 206-220.

Richards, F.A. with T.G. Thompson. 1952. The estimation and characterization of plant populations by pigment analyses. II. A spectro-photometric method for the estimation of plankton pigments. *J. Mar. Res.,* **11:** 156-172.

Riley. G.A., H. Stommel and D.F.Bumpus. 1949. Quantitative ecology of the plankton of the Western North Atlantic. *Bull. Bingham Oceanogr. Coll*., **12**: art. 3.

Ryther, J.H. 1956. The measurement of primary production. *Limnol. Oceanogr*., **1**(2): 72-84.

Ryther, J.H. 1959. The potential productivityof the sea. *Science,***130**: 602-608.

Ryther, J.H. 1963. Geographic variations in productivity. In "The Sea" Ed. M.N. Hill. Intersc. Publ., London: 347-380.

Ryther, J.H. and D.W. Menzel. 1965. On the production, composition and distribution of organic matter in the western Arabian Sea. *Deep Sea Res*., **12**: 199-210.

Ryther, J.H. and C.S. Yensch. 1957. The estimation of phytoplankton production from chlorophylls and light data. *Limnol, Oceanogr.* **2**: 281-286.

Ryther, J.H. J.R. Hall, A.K. Pease, A. Bakun and M.M. Jones. 1966. Primary organic production in relation to the chemistry and hydrography of the western Indian ocean. *Limnol. Oceanogr*., **11**(3): 107-113.

Sankaranarayanan, V.N. and C.V.G. Reddy. 1968. Nutrients of the north western Bay of Bengal. *Bull. Natn. Inst. Sci. India.* No. 38: 148-163.

Schaefer, M.B. 1965. The pontential harvest from the sea. *Trans. Amer. Fish. Soc.*, **94**(2): 123-128.

Sorkin, J.I, 1958. The results and prospects of using radioactive C^{14} for a study of organic matter cycle in water basins. Radioisotopes in scientific research. *Proc. 1st*(*UNESCO*) *Intern. Conf.*, **4**: 633.

Steele, J.H. 1956. Plant production on the Fladen ground. *J. Mar. biol. Ass. U.K*., **35**: 1-33.

Steele, J.H. 1958. Production studies in the northern North Sea. *Rapp. Proc-Verb. Cons, Expl. Mer*., **144**: 79-84.

Steele, J.H. 1961. Primary Production. In Oceanography. Ed. M. Sears. Publ. No. 67 of A.A.A.S., Washington, 519-538.

Steemann Nielsen, E. 1952. The use of radio-active carbon (C^{14}) for measuring organic production in the sea. *J. cons. Int. Explor. Mer.,* **18**: 117-140.

Steemann Nielsen, E. 1958. Experimental methods for measuring organic production in the sea. *Rapp. Proc. Verb. Cons. Expl. Mer*. **144:**38-46

Steemann Nielsen, E. 1958a. Light and organic production in the sea. *Ibid*., **144**: 141-148.

Steemann Nielsen, E. 1960. Productivity of the oceans. *Ann. Rev. Plant Physiol*., **11**: 341-362.

Steemann Nielsen, E. 1962. On the biology of the Indian Ocean. *ISCU Review*, **4(**1962) : 9-13.

Steemann Nielsen, E. 1963. Productivity, definition and measurement . In "The Sea", Vol. 2 (Ed.M.N. Hill). Intersc. Publ., 129-164.

Steemann Nielsen, E. 1965. On the determination of the activity in C-14 ampoules for measuring primary production. *Limnol. Oceanogr.* **10**(suppl), R. 247-R252.

Steemann Nielsen, E. and E.A. Jensen 1957. Primary Oceanic production. The autotrophic production of organic matter in the oceans. *Galathea Repts*., **1**: 49-136.

Steemann Nielsen, E. and V.K. Hansen 1959. Measurement with the carbon-14 technique of the respiration rates in natural populations of phytoplankton *Deep Sea Res*., **5:** 222-223.

Strickland, J.D.H. 1958. Solar radiation penetrating the ocean. A review of requirements data and methods of measurement with particular reference to photosynthtic productivity. *J. Fish. Res. M. Canada*, **15**: 453-493.

Strickland, J.D.H. 1960. Measuring the production of marine phytoplankton. *Ibid*., **122**: 1-172.

Strickland, J.D.H. 1961. Significance of the values obtained by primary production measuremtns. *Proc. Conf. Primary Productivity Measurement. Mar. & Fresh*. Ed. M.S. Doty, Univ. Hawaii. U.S. Atomic Energy Comm. TID-7633. 172-183.

Strickland, J.D.H. 1963. Phytoplankton productivity, In Riley, G.A. Marine Biology I. *Proc. First Intl. Interdisc. Conf.* American Inst. of Biological Sciences, Washington DC, 105-206.

Strickland, J.D.H. 1965. Production of organic matter in the primary stages of the marine food chain. Ed. Riley and Skirrow. Chemical oceanography: 478-595.

Subrahmanyan, R. 1959. Studies on the phytoplankton of the west coast of India Part I. *Proc. Indian Acad. Sci*., **50**B: 113-187.

Utermohl, H.1931. Neu Wege in der quantitativen Erfassung des Planktons. *Verh. Int. Ver. Limnol*., **5**

Vollenweider, R.A. (Ed.) 1969. A manual on methods for measuring primary production in aquatic environments. IBP Handbook No. 12. Blackwell Sc. Publ. Oxford, 213 pp.

Yentsch C.S. 1963. Primary production. *Oceanogr. Mar. Biol. Ann. Rev.*, **1**: 157-175.

Yentsch C.S. and D.W. Menzel. 1963. A method for the determination of phytoplankton chlorophyll and phaeophytin by fluorescence. *Deep-Sea Res.*, **10**: 221-231.

APPENDIX I

Conversion of pH to hydrogen ion activity from the relation $aH = 10^{-pH}$. For a pH of Q+v (Where v is the decimal part) find N from the Table in terms of v and substitute in the equation.
$aH = Nx10^{-Q}$.

v	N	v	N	v	N
0.00	1.000	0.34	0.457	0.67	0.214
0.01	0.977	0.35	0.447	0.68	0.209
0.02	0.955	0.36	0.437	0.69	0.204
0.03	0.933	0.37	0.427	0.70	0.200
0.04	0.912	0.38	0.417	0.71	0.195
0.05	0.891	0.39	0.407	0.72	0.191
0.06	0.871	0.40	0.398	0.73	0.186
0.07	0.851	0.41	0.389	0.74	0.182
0.08	0.832	0.42	0.380	0.75	0.178
0.09	0.813	0.43	0.372	0.76	0.174
0.10	0.794	0.44	0.363	0.77	0.170
0.11	0.776	0.45	0.355	0.78	0.166
0.12	0.759	0.46	0.347	0.79	0.162
0.13	0.741	0.47	0.339	0.80	0.158
0.14	0.725	0.48	0.331	0.81	0.155
0.15	0.709	0.49	0.324	0.82	0.151
0.16	0.692	0.50	0.316	0.83	0.148
0.17	0.676	0.51	0.309	0.84	0.144
0.18	0.661	0.52	0.302	0.85	0.141
0.19	0.646	0.53	0.295	0.86	0.138
0.20	0.631	0.54	0.288	0.87	0.135
0.21	0.617	0.55	0.282	0.88	0.132
0.22	0.603	0.56	0.275	0.89	0.129
0.23	0.589	0.57	0.269	0.90	0.126
0.24	0.575	0.58	0.263	0.91	0.123
0.25	0.562	0.59	0.257	0.92	0.120
0.26	0.549	0.60	0.251	0.93	0.117
0.27	0.537	0.61	0.245	0.94	0.115
0.28	0.525	0.62	0.240	0.95	0.112
0.29	0.513	0.63	0.234	0.96	0.110
0.30	0.501	0.64	0.229	0.97	0.107
0.31	0.490	0.65	0.224	0.98	0.105
0.32	0.479	0.66	0.219	0.99	0.102
0.33	0.468				

APPENDIX II

Factors for total alkalinity measurement.
Factor f in the Equation:
Total alkalinity = 2.500-1250 aH/f as a function of chlorinity or salinity

pH	$CL^0/_{00}$	2	4	6	8	10	12-18	20
range	$S^0/_{00}$	3.5	7	11	14.5	18	21-33	36
		f	f	f	f	f	f	f
2.8-2.9		0.865	0.800	0.785	0.775	0.770	0.768	0.773
3.0-3.9		0.845	0.782	0.770	0.760	0.755	0.753	0.758
4.0		0.890	0.822	0.810	0.800	0.795	0.793	0.798

APPENDIX III

Conversion of total alkalinity to carbonate alkalinity.
Quantity, A, milliequivalents per litre, to be subtracted from the total alkalinity to give the carbonate alkalinity in milliequivalents per litre.
Note. Multiply the value in the table by 10^{-2} to get A.

pHs (d)	^{0}C=0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30
					Cl = 15$^0/_{00}$							S = 27$^0/_{00}$				
7.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
7.4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2
7.5	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2
7.6	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2
7.7	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3
7.8	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	4
7.9	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4
8.0	3	3	4	4	4	4	4	4	4	5	5	5	5	5	5	5
8.1	4	4	4	4	5	5	5	5	5	5	6	6	6	6	6	6
8.2	5	5	5	5	6	6	6	6	6	7	7	7	7	7	8	8
8.3	6	6	6	7	7	7	7	7	8	8	8	8	9	9	9	9
8.4	7	7	8	8	8	8	9	9	9	9	10	10	10	10	11	11
8.5	8	9	9	9	10	10	10	10	11	11	11	11	12	12	12	13
8.6	10	10	11	11	11	12	12	12	12	13	13	13	14	14	14	14
8.7	12	12	12	13	13	13	14	14	14	14	15	15	16	16	16	16
8.8	15	15	15	15	16	16	17	17	17	17	18	18	18	19	19	19
					Cl = 17$^0/_{00}$							S = 31$^0/_{00}$				
7.3	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1
7.4	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2
7.5	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2
7.6	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3
7.7	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	4
7.8	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4
7.9	3	3	3	4	4	4	4	4	4	4	5	5	5	5	5	5
8.0	4	4	4	4	5	5	5	5	5	5	6	6	6	6	6	6
8.1	5	5	5	5	6	6	6	6	6	7	7	7	7	8	8	8
8.2	6	6	6	6	7	7	7	7	8	8	8	8	9	9	9	9
8.3	7	7	8	8	8	8	9	9	9	9	10	10	10	11	11	11
8.4	8	9	9	9	10	10	10	11	11	11	11	12	12	12	13	13
8.5	10	10	11	11	11	12	12	12	13	13	13	14	14	14	15	15
8.6	12	12	13	13	13	14	14	14	15	15	15	16	16	16	17	17
8.7	14	14	15	15	16	16	16	16	17	17	18	18	18	19	19	19
8.8	17	17	18	18	19	19	19	20	20	20	21	21	21	22	22	23

APPENDIX III (Contd.)

pHs (d)	^{0}C=0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30
					Cl = 19$^0/_{00}$						S = 34$^0/_{00}$					
7.3	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1
7.4	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2
7.5	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3
7.6	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3
7.7	2	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4
7.8	3	3	3	3	4	4	4	4	4	4	4	5	5	5	5	5
7.9	4	4	4	4	4	5	5	5	5	5	5	6	6	6	6	6
8.0	5	5	5	5	5	6	6	6	6	6	7	7	7	7	7	8
8.1	6	6	6	6	7	7	7	7	8	8	8	8	8	9	9	9
8.2	7	7	7	8	8	8	9	9	9	9	10	10	10	10	11	11
8.3	8	9	9	9	10	10	10	10	11	11	11	12	12	12	13	13
8.4	10	10	11	11	11	12	12	12	13	13	13	14	14	14	15	15
8.5	12	12	13	13	13	14	14	14	15	15	16	16	16	17	17	17
8.6	14	14	15	15	16	16	16	17	17	18	18	18	19	19	19	20
8.7	16	16	17	17	18	18	19	19	19	20	20	20	21	21	22	22
8.8	19	20	20	21	21	22	22	22	23	23	24	24	24	25	25	25
					Cl = 21$^0/_{00}$						S = 38$^0/_{00}$					
7.3	0	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2
7.4	1	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3
7.5	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3
7.6	2	2	2	3	3	3	3	3	3	3	3	4	4	4	4	4
7.7	3	3	3	3	3	4	4	4	4	4	4	4	4	5	5	5
7.8	4	4	4	4	4	4	5	5	5	5	5	5	6	6	6	6
7.9	4	4	5	5	5	5	6	6	6	6	6	7	7	7	7	7
8.0	5	6	6	6	6	7	7	7	7	7	8	8	8	8	9	9
8.1	7	7	7	7	8	8	8	8	9	9	9	10	10	10	10	11
8.2	8	8	9	9	9	10	10	10	10	11	11	11	12	12	12	13
8.3	10	10	10	11	11	11	12	12	12	13	13	14	14	14	15	15
8.4	11	11	11	12	12	13	13	13	14	14	14	15	15	15	16	16
8.5	14	14	14	15	15	16	16	17	17	17	18	18	19	19	20	20
8.6	16	16	17	17	18	18	19	19	20	20	21	21	22	22	22	23
8.7	18	19	19	20	20	21	21	22	22	23	23	24	24	24	25	25
8.8	22	22	23	23	24	24	25	25	26	26	27	27	28	28	28	29

APPENDIX IV

Conversion of carbonate alkalinity to total carbon dioxide
Factor, F_T, in the equation:

Total carbon dioxide content = carbonate alkalinity x F_T.

pHs (d)	^{0}C=0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30
					Cl = 15$^0/_{00}$						S = 27$^0/_{00}$					
7.3	1.07	1.06	1.06	1.06	1.05	1.05	1.05	1.05	1.04	1.04	1.04	1.04	1.03	1.03	1.03	1.03
7.4	1.05	1.05	1.04	1.04	1.04	1.04	1.03	1.03	1.03	1.03	1.03	1.02	1.02	1.02	1.02	1.02
7.5	1.04	1.03	1.03	1.03	1.03	1.02	1.02	1.02	1.02	1.02	1.01	1.01	1.01	1.01	1.01	1.00
7.6	1.02	1.02	1.02	1.02	1.02	1.01	1.01	1.01	1.01	1.01	1.00	1.00	1.00	1.00	.99	.99
7.7	1.01	1.01	1.01	1.01	1.00	1.00	1.00	1.00	1.00	.99	.99	.99	.99	.99	.98	.98
7.8	1.00	1.00	1.00	1.00	.99	.99	.99	.99	.99	.98	.98	.98	.98	.97	.97	.97
7.9	.99	.99	.99	.99	.98	.98	.98	.98	.98	.97	.97	.97	.97	.96	.96	.96
8.0	.98	.98	.98	.98	.97	.97	.97	.97	.96	.96	.96	.96	.95	.95	.95	.94
8.1	.97	.97	.97	.97	.96	.96	.96	.96	.95	.95	.95	.94	.94	.93	.93	.93
8.2	.96	.93	.96	.95	.95	.94	.95	.94	.94	.93	.93	.93	.92	.92	.91	.91
8.3	.95	.95	.94	.94	.94	.93	.93	.93	.92	.92	.91	.91	.90	.90	.89	.89
8.4	.93	.93	.93	.92	.92	.92	.91	.91	.90	.90	.89	.89	.88	.88	.87	.86
8.5	.92	.91	.91	.91	.90	.90	.89	.89	.88	.88	.87	.86	.86	.85	.85	.84
8.6	.90	.89	.89	.89	.88	.88	.87	.87	.86	.85	.85	.84	.83	.83	.82	.81
					Cl = 17$^0/_{00}$						S = 31$^0/_{00}$					
7.3	1.06	1.06	1.06	1.05	1.05	1.05	1.04	1.04	1.04	1.04	1.04	1.03	1.03	1.03	1.03	1.03
7.4	1.05	1.04	1.04	1.04	1.04	1.03	1.03	1.03	1.03	1.02	1.02	1.02	1.02	1.02	1.02	1.01
7.5	1.03	1.03	1.03	1.02	1.02	1.02	1.02	1.02	1.01	1.01	1.01	1.01	1.01	1.01	1.00	1.00
7.6	1.02	1.02	1.02	1.01	1.01	1.01	1.01	1.01	1.00	1.00	1.00	1.00	1.00	.99	.99	.99
7.7	1.01	1.01	1.01	1.00	1.00	1.00	1.00	1.00	.99	.99	.99	.99	.98	.98	.98	.98
7.8	1.00	1.00	1.00	.99	.99	.99	.99	.98	.98	.98	.98	.98	.97	.97	.97	.96
7.9	.99	.99	.99	.98	.98	.98	.98	.97	.97	.97	.97	.96	.96	.96	.95	.95
8.0	.98	.98	.97	.97	.97	.97	.96	.96	.96	.96	.95	.95	.95	.94	.94	.94
8.1	.97	.97	.96	.96	.96	.95	.95	.95	.95	.94	.94	.94	.93	.93	.92	.92
8.2	.96	.95	.95	.95	.94	.94	.94	.93	.93	.93	.92	.92	.92	.91	.91	.90
8.3	.94	.94	.94	.93	.93	.92	.92	.92	.91	.91	.90	.90	.90	.89	.88	.88
8.4	.93	.92	.92	.92	.91	.91	.90	.90	.89	.89	.88	.88	.87	.87	.86	.86
8.5	.91	.91	.90	.90	.89	.89	.88	.88	.87	.87	.86	.86	.85	.84	.84	.83
8.6	.89	.89	.88	.87	.87	.86	.86	.85	.85	.84	.84	.83	.82	.82	.81	.80

APPENDIX IV (Contd.)

pHs (d)	^{0}C=0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30
					Cl = 19$^0/_{00}$						S = 34$^0/_{00}$					
7.3	1.06	1.06	1.05	1.05	1.05	1.04	1.04	1.04	1.04	1.03	1.03	1.03	1.03	1.03	1.02	1.02
7.4	1.04	1.04	1.04	1.03	1.03	1.03	1.03	1.03	1.02	1.02	1.02	1.02	1.02	1.01	1.01	1.01
7.5	1.03	1.03	1.02	1.02	1.02	1.02	1.02	1.01	1.01	1.01	1.01	1.01	1.00	1.00	1.00	1.00
7.6	1.02	1.02	1.01	1.01	1.01	1.01	1.00	1.00	1.00	1.00	1.00	.99	.99	.99	.99	.99
7.7	1.01	1.00	1.00	1.00	1.00	1.00	.99	.99	.99	.99	.99	.98	.98	.98	.98	.98
7.8	1.00	.99	.99	.99	.99	.99	.98	.98	.98	.98	.97	.97	.97	.97	.96	.96
7.9	.99	.98	.98	.98	.98	.97	.97	.97	.97	.96	.96	.96	.96	.95	.95	.95
8.0	.98	.97	.97	.97	.96	.96	.96	.96	.95	.95	.95	.94	.94	.94	.93	.93
8.1	.96	.96	.96	.96	.95	.95	.95	.94	.94	.94	.93	.93	.93	.92	.92	.92
8.2	.95	.95	.95	.94	.94	.94	.93	.93	.92	.92	.92	.91	.91	.90	.90	.90
8.3	.94	.93	.93	.93	.92	.92	.91	.91	.91	.90	.90	.89	.89	.88	.86	.88
8.4	.92	.92	.91	.91	.90	.90	.90	.89	.89	.88	.88	.87	.86	.86	.85	.85
8.5	.90	.90	.89	.89	.88	.88	.87	.87	.86	.86	.85	.85	.84	.83	.83	.83
8.6	.88	.88	.87	.87	.86	.86	.85	.84	.84	.83	.83	.82	.81	.81	.80	.80
					Cl = 21$^0/_{00}$						S = 38$^0/_{00}$					
7.3	1.06	1.05	1.05	1.04	1.04	1.04	1.04	1.04	1.03	1.03	1.03	1.03	1.02	1.02	1.02	1.02
7.4	1.04	1.04	1.03	1.03	1.03	1.03	1.02	1.02	1.02	1.02	1.02	1.01	1.01	1.01	1.01	1.01
7.5	1.03	1.02	1.02	1.02	1.02	1.02	1.01	1.01	1.01	1.01	1.00	1.00	1.00	1.00	1.00	1.00
7.6	1.01	1.01	1.01	1.01	1.01	1.00	1.00	1.00	1.00	.99	.99	.99	.99	.99	.98	.99
7.7	1.00	1.00	1.00	1.00	.99	.99	.99	.99	.99	.98	.98	.98	.98	.97	.97	.97
7.8	.99	.99	.99	.99	.98	.98	.98	.98	.97	.97	.97	.97	.96	.96	.96	.96
7.9	.98	.98	.98	.97	.97	.97	.97	.97	.96	.96	.96	.95	.95	.95	.94	.94
8.0	.97	.97	.97	.96	.96	.96	.96	.95	.95	.95	.94	.94	.94	.93	.93	.93
8.1	.96	.96	.95	.95	.95	.95	.94	.94	.93	.93	.93	.92	.92	.91	.91	.91
8.2	.95	.94	.94	.94	.93	.93	.93	.92	.92	.91	.91	.90	.90	.89	.89	.89
8.3	.93	.93	.92	.92	.92	.91	.91	.90	.90	.89	.89	.88	.88	.87	.86	.86
8.4	.91	.91	.91	.90	.90	.89	.89	.88	.88	.87	.87	.86	.85	.85	.84	.84
8.5	.89	.89	.89	.88	.88	.87	.86	.86	.85	.85	.84	.84	.83	.82	.81	.81
8.6	.87	.87	.86	.86	.85	.85	.84	.83	.83	.82	.82	.81	.80	.79	.79	.78