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STUDIES ON THE PHYTOPLANKTON OF THE WEST COAST OF INDIA

Part I. Quantitative and Qualitative Fluctuation of the Total Phytoplankton Crop, The Zooplankton Crop and Their Interrelationship, with Remarks on the Magnitude of the Standing Crop and Production of Matter and Their Relationship to Fish Landings

By

R. SUBRAHMANYAN

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I. INTRODUCTION

N the temperate and polar waters considerable work has been done on the [ualitative and quantitative fluctuation of the phytoplankton as well as on heir production and rate of production of other organic matter by them; .nd, consequently, we have a good knowledge of the fertility of these waters.)n the other hand, our knowledge about these aspects of the tropical and ub-tropical zones of the world is very meagre indeed, and all our knowledge .bout these regions until very recently was derived from the reports of Expedi- ions (the *Challenger*, *Valdivia*, *Meteor*, *Michæl Sars*, *Carniegie*, *John Murray*, *Dana* and so on) and as has been pointed out with emphasis by Dakin and Colefax (1940) these reports are often misleading as to the true conditions ind give one an erroneous picture of the plankton conditions of the warmer 'egions, mainly because the conclusions are based on casual and disconti- nuous observations made during off-seasons while passing through the ropical regions to reach the temperate zones at or during the favourable ,eason there.

Further, it is generally held that tropical waters are not so productive is compared with the colder seas. Some of the investigations in recent times iave shown, however, that when all facts are taken into consideration,—the ncreased metabolic rate in the warmer regions, the rate of turnover, and the 'requent records of heavy crops of zooplankton in certain areas—tropical ind sub-tropical waters also are to be considered productive when compared vith the colder regions (Russel, 1934 *b*; Russel and Coleman, 1934; Allen, .924, 1934 and 1939; Seiwell, 1935 *a*; Gilson, 1937; Dakin and Colefax, 1940; Riley, 1938, 1939, 1944; Riley, Stommel and Bumpus, 1949; Graham, 1941 *a*; and King and Demond, 1953; *cf.* however Steemann Nielsen, 1951 *a*, 1952, 1954). Again, certain areas near the shore in the warmer regions are known to support a heavy crop of plankton such as the west coast of Africa (Hentschel and Wattenberg, 1930) and the west coast of S. America (Gunther, 1936). According to Graham (1941 *a*) plankton production is not a function of lattitude but depends upon presence of "new water" high in nutrient salts. He found greater production of total plankton in the tropics between 20° N. and 11° S. than between 20° and 34° N. in the Pacific.

Data relating to phytoplankton of the warmer seas in particular are very meagre. Marshall (1933) has indicated that production of phytoplankton in the Great Barrier Reef region is not poor when compared with certain temperate regions like the English Channel. Gilson (1937, p. 59) after a study of the northern part of the Indian Ocean, including stations in the Arabian Sea, states that "Whatever the value of comparison, it is probably safe to say that the productivity of the tropical upwelling areas exceeds that of any temperate sea, while the open tropical ocean is by no means as barren as has commonly been supposed, and is indeed comparable in this respect with a region such as the English Channel". Allen (1939) has recorded heavy production of phytoplankton in the Panama region. Kow (1953, p. 41) states that the standing crop in the Singapore Straits is not very much lower than that in the English Channel. There are a few accounts by Japanese workers dealing with the plankton of the tropical regions in the Pacific (Aikawa, 1942; Kitou, 1952; Motoda, 1940 and 1941; Tokioka, 1942 *a*, 1942 *b*; and Haneda, 1942). The results of Haneda and Tokioka show higher volumes of plankton nearer the Equator.

In India there have been several attempts in the past to study the marine plankton of both the east and west coasts of the Peninsula (Hornell and Nayudu, 1923; Menon, 1931; Aiyar, Menon and Menon, 1936; Menon, 1945; Chacko, 1950; Chidambaram and Menon, 1945; George, 1953 *a*; Gonzalves, 1947; Prasad, 1954 *a* and 1956; Ganapati and Murthy, 1955; Ganapati and Rao, 1953; and Ramamurthy, 1953 *b*). All these accounts are of a general nature and the duration of the investigations varies from a few months to about three years only. They are, further, all of a qualitative nature with indications of the peak period of plankton production and of the seasonal cycle (Panikkar, 1950). None of the accounts appear to give a quantitative assessment of the crop of plankton in the sea, least of all phytoplankton, the prime synthesizers of food. Most of the accounts, further, claim to be of a preliminary nature and, therefore, do not allow of any definite conclusions to be drawn.

It may be mentioned here that in India in the past, investigations on the phytoplankton in particular appear to have suffered due to the want of a taxonomical appraisal of the constituents of the flora; this may be true of many other regions also. This has been remedied to some extent by the account of Subrahmanyan (1946) for the Diatomaceæ, the group which constitutes the bulk of the plankton flora.

The writer studied the phytoplankton from all aspects in the scheme of fisheries research recently initiated in India; and, since 1949, he has been engaged in this work. In the present paper, which forms the first part, an account is given of the seasonal fluctuation of the total quantity of the phytoplankton crop and the main groups constituting the same, the total zooplankton crop, the magnitude of the standing crop compared with other regions, the interrelationship between phyto- and zoo-plankton crops, and the results are discussed with reference to fish landings and also compared with those from other geographical areas. Being the first paper from this country on such an aspect of quantitative study on plankton, some pertinent literature has also been reviewed for comparison and relative assessment of the fertility of the waters. This investigation covers a period of over five years and it was extended to such a long period as it was the desire to report, as far as possible, definite and reliable conclusions in the interests of future applied research. In the second part the physical and chemical factors involved in the production of phytoplankton and the relationship of some of the former to fish landings are dealt with.

II. Physical and Meteorological Features of the West Coast of India

For a clear appreciation of the results presented in the following pages and the ecological relationships, a knowledge of the physical features and meteorological conditions of the area is necessary. Particulars given in this section have been drawn from Admiralty (1950) publication, Hornell and Nayudu (1923), Bristow (1938) and Du Cane *et al.* (1938). The meteorological data were obtained through the courtesy of the Director, Regional Meteorological Centre, Madras.

1. *Physical Features*

The west coast of Peninsular India forms a narrow belt of low land, geologically of laterite formation, lying between the sea and the Western Ghats which extend the whole length of the Peninsula varying in width from 20 to 100 miles inland. There is a large number of short rivers many of which discharge into backwaters of varying breadth occurring parallel to the coast. There are two rivers nearer to the present area of investigation—the Kallai on the south and Elathur on the north, both of which open into the sea (Text-Fig. 3).

The coast-line (Bristow, 1938) north of Calicut up to Mount Delli is fringed with low cliffs alternating with reaches of sand; and denuded headlands and bays hollowed out by the waves on their southward side betray the action of the ocean current. At Calicut and southwards the shore is one unbroken stretch of sand partly thrown up by the waves, partly formed by alluvial deposits brought down by the rivers and backwaters.

2. *Meteorological Features*

(*a*) *Seasons.*—The climate of the west coast of India in particular is dominated by the monsoons and four seasons could be distinguished*:

(1) A wet season (May–June to September): The onset of the south-west monsoon is the beginning of the rainy season for most of the region. It commences in May or early in June, exceptionally later in some years by the end of June, at the southern end of Peninsula and advances northwards striking the coast of Sind (Pakistan) in about three weeks.

(2) A short transition period, comprising the end of September and October, hot, steamy, fairly dry season occurs before the north-east monsoon sets in.

(3) The north-east monsoon normally begins earlier in the north than in the south where it becomes well established by December. It continues until about March in which month it becomes unsteady in the south. During this season, there is practically no rainfall on the west coast.

(4) A hot dry season, March and April, characterised by calm weather with light breezes from north north-west and north-west. In May, conditions again become unsettled indicating the onset of the south-west monsoon.

(*b*) *Wind force.*—The wind force at Calicut in the months prior to the outbreak of the south-west monsoon proper is rather high owing to the high temperature and consequent low pressure over the region. With the outbreak of the monsoon proper, the wind force tends to diminish, rises slightly in October (the transition month to the north-east monsoon), falls again a little but increases steadily from January onwards. The data relating to wind force at Calicut are shown in Table I.

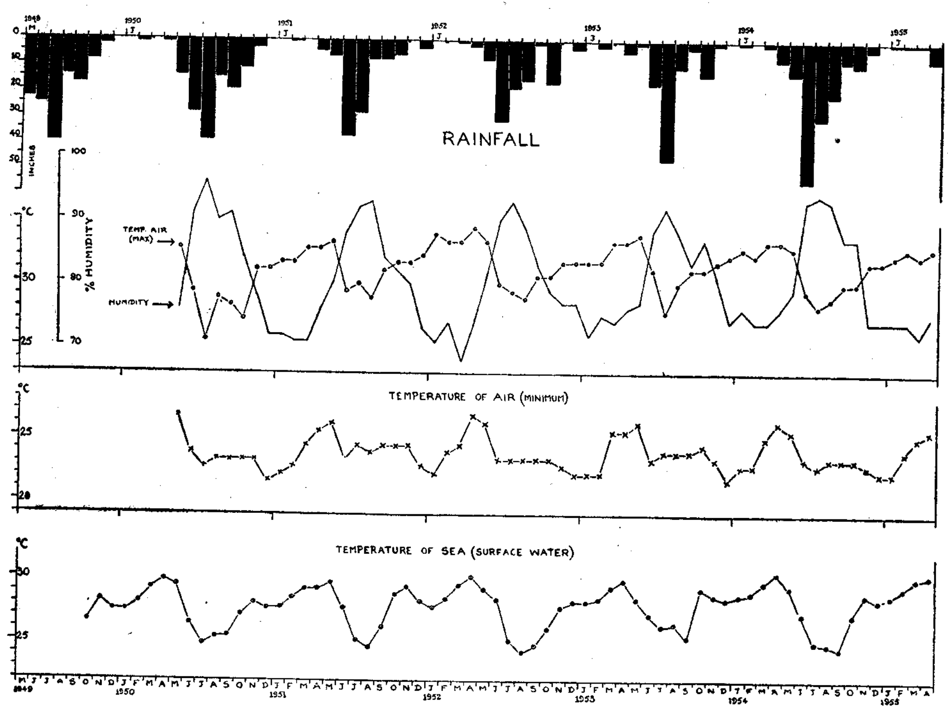
(*c*) *Rainfall.*—The annual rainfall is high over the region varying from 60–130 inches. Most of it falls during the south-west monsoon season. North of 20° rainfall is somewhat less. During the north-east monsoon season, there is very little rainfall over the region.

* More details may be had from Admiralty (1950) publication.

TABLE I

Wind velocity (Miles per hour)

Month / Year	1949–50	1950–51	1951–52	1952–53	1953–54	1954–55	Average of 5 years
May ..	7·7	9·8	8·0	8·0	9·9	8·0	8·6
June ..	5·7	7·5	7·1	5·7	7·1	5·7	6·6
July ..	6·3	5·7	7·0	5·5	6·9	5·5	6·2
August ..	5·6	5·6	5·5	5·3	6·5	6·0	5·8
September ..	5·6	6·2	5·8	5·4	5·7	4·9	5·6
October ..	6·3	6·1	6·0	7·9	5·5	5·5	6·2
November ..	5·4	5·6	5·4	6·2	5·5	5·9	5·6
December ..	6·0	5·7	5·7	5·5	5·7	5·7	5·7
January ..	6·8	6·5	6·1	6·7	6·0	6·5	6·4
February ..	8·7	7·5	7·0	6·9	7·4	8·1	7·6
March ..	8·0	8·0	8·0	8·9	7·6	8·5	8·2
April ..	9·5	9·1	8·2	8·5	8·3	8·3	8·7



TEXT-FIG. 1. Seasonal fluctuation of the temperature of air (maximum and minimum), of water, humidity and total rainfall.

At Calicut, the mean annual rainfall is over 100 inches; over 50% of it falls in the month of June and July of the south-west monsoon season. The total rainfall was 138·4 inches in 1949; it declined during the succeeding years to 92·16 inches in 1952; then rose to 95·7 inches in 1953 and 143·20 inches in 1954 (Text-Fig. 1). The records of rainfall for over several decades (1864–1937) at Cochin (9·58° N., 76·17° E.), south of Calicut, indicate two outstanding peaks, one in 1882 and the second in 1924 and a fairly average succession of medium, high and low intensity during the years in-between (Bristow, 1938). A possibility of a similar cyclical occurrence of rainfall is indicated at Calicut also by the data collected here.

The rainfall at sea about 20 miles from the Malabar and Konkan coasts is believed to be considerably less than on the coast.

(*d*) *Air temperature and humidity*.—The temperature is high over most of the region. The maximum temperature varies from 27·7° C. to 33·3° C. The mean temperature in the hottest month, which is generally just before the onset of the south-west monsoon, is nearly the same over most of the places, but the mean of the coolest month differs considerably.

The temperature of air at Calicut is fairly high (Text-Fig. 1). The highest value for the maximum lies in April (1952–55) or May (1951) and the lowest in July (1953 and 1954) or August (1951 and 1952). The highest value for the minimum temperature also occurs in April or May but the lowest minimum temperature is recorded in December or January. The range between the maximum and minimum is highest in January (average 10·2° C.) and is least during the south-west monsoon months of June and July (average 4·8° C.). A double oscillation in the fluctuation of the temperature of air is evident, clearly expressed when the average daily temperatures are reckoned. The main maximum occurs in April or May and with the onset of the south-west monsoon, the temperature falls till July or August when the difference between the maximum and the minimum is least; then, the temperature rises again and shows a minor peak in October or November (transition months to the north-east monsoon season) after which there is a slight fall in the maximum, but a much greater fall in the minimum value, when the daily range between the two is greatest (December or January), the winter or cold season of the region. (The temperature of the sea surface at Calicut is given and discussed in Part II.)

The *humidity* over the area is very high. It varies from 80–90% during the south-west monsoon months and 65–75% during the north-east monsoon months.

The humidity at Calicut (Text-Fig. 1) during the years of investigation varied from 68% (March 1952) to 94% (June 1954). The mean variation (average of 5 years) at Calicut during the south-west monsoon period is from 79–93%; from May it increases up to July and falls subsequently. During the north-east monsoon season it varies from 72–78%, the lowest value being in March. Humidity increases as rainfall increases and temperature falls. The north-east monsoon is not very active on the western side of the Ghats and there is no appreciable rain after October, the transition month between the monsoons. The humidity, therefore, registers a fall and begins to rise again when the pre-monsoon rains fall in the April following.

From the marine biological aspect, the year may be divided into two periods: (1) the south-west monsoon period from May to September–October and (2) the north-east monsoon period, October–November to April.

III. The Sea Floor, Mud Banks and Currents

1. *Sea Floor*

The Continental shelf (Brown in Du Cane *et al.*, 1938) on the west coast of India extends outward to an average depth of 100 fathoms and at about

20° N. latitude is widest, being over 120 miles and narrows to the south until, off Cape Comorin, it is only 30 miles wide. The 100 fathom contour line has well marked indentations, one north of Cochin and another south of Quilon where the shelf is constricted to about 25 miles or less. The sea floor slopes gradually to a depth of 100 fathoms along the Malabar Coast and makes a steep descent to great depths. Off Mangalore-Cochin section, the sea floor slopes very gradually to about 65 fathoms; beyond, the bottom plunges to the 1,000 fathom line. At about Quilon, south of Calicut, the shelf first slopes to as much as 190 fathoms and then rises to 170 fathoms before falling away steeply in the Continental slope.

The sea bottom, according to Hornell (1910) "from about a mile from shore out to 30 fathoms, from Ponnani northwards to Mangalore, is composed of soft grey mud with small dead shells, etc.". It is believed (Du Cane *et al.*, 1938) that the mud deposits are terrigeneous in character and largely derived from the laterite and alluvial belt of the coast which originated from the disintegration of gneissic rocks of the interior. Mud of both sea bed and mud banks (mentioned below) are thought to be brought down by the present and past rivers.

2. *Mud Banks* (Bristow, 1938; Du Cane *et al.*, 1938)

There are four well-known mud banks off the south-west coast of India, one at Alleppey, one at Cochin, and two at or near Calicut. Mud banks of a less intense nature occur at Quilandy, Tellicherry and a few other places. These banks are formed by fine mud which is in an unconsolidated state and the banks shift from place to place under certain influences which are not clearly understood. Earthquakes and underwater cataclysmic changes and cyclones as also ocean currents have been known to affect the movement of the mud banks at Cochin. Further, the intensity of rainfall is supposed to affect the silting at the approaches in Cochin and the movement of the Narakkal mud bank nearby.

The mud banks at Calicut also are known to shift from place to place and appear or disappear probably depending on the intensity of rainfall and coastal currents. Generally, they become visible during the south-west monsoon season and occur slightly submerged or well visible out of the water at a little distance from the shore. One characteristic feature, when they are present here as well as elsewhere, is that the sea in their environs remains extremely calm even when the roughest weather prevails and the water is very stormy in the surrounding areas. In the region of the mud banks, the water surface has been found to be oily (the oil has similarity to petroleum);

this was believed to effect the calm conditions (Bristow, 1938) ; however, this effect is supposed to be due to the suspension of fine matter increasing the viscosity of the water which helps break up the force of the waves (Keen in Du Cane *et al.*, 1938, pp. 52–54).

The mud banks appear to play an important part in the biology and chemistry of the sea-water in these parts, details of which will be referred to in the appropriate sections.

About 200 miles westward of the coast, a chain of coral islands, the Laccadives, is present extending north-south and the portion of the sea between these islands and the mainland is known as the Laccadive Sea. At Calicut itself (Admiralty, 1950) there are a few reefs present which remain submerged. They are situated about 2–3 miles south of the sampling stations of the present investigation.

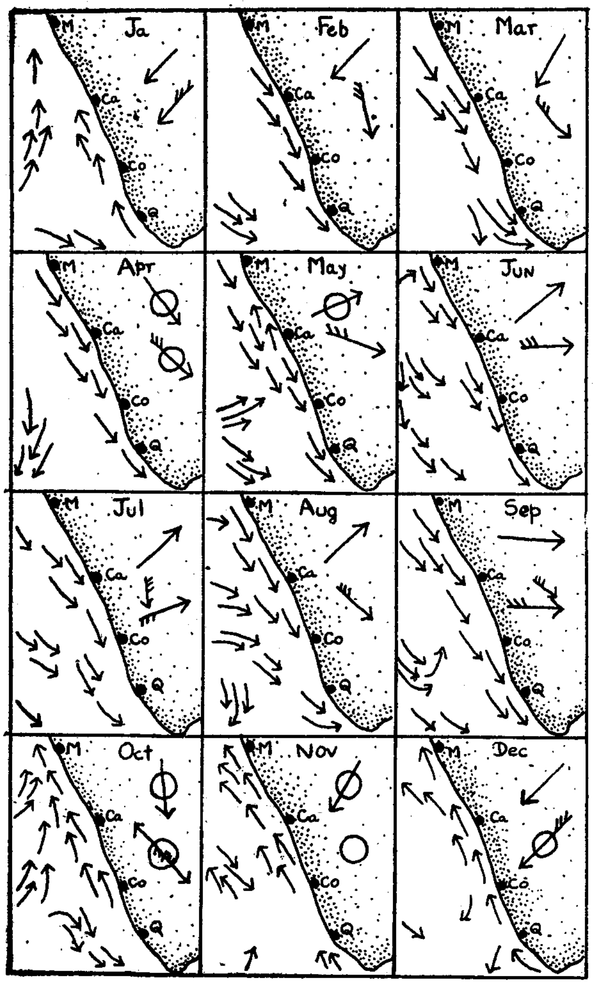
3. *Ocean Currents* (Admiralty, 1950; Sewell, 1929; Möller, 1929) ; (Text-Fig. 2)

In the northern part of the Indian Ocean, the monsoons develop seasonal surface currents in opposite directions, according to the time of the year. The east-going Equatorial Countercurrent, however, though lying mainly south of the Equator extending a few degrees north of the Equator, is not reversed.

During the south-west monsoon, the coastal current in the Arabian Sea and Bay of Bengal sets in a clockwise direction owing to the coastal conformation; and in a counterclockwise direction from November to January, during the height of the north-east monsoon. In the more open parts of the seas, the current takes the direction of a drift current due to the monsoon blowing at the time. This direction is easterly during the south-west monsoon and westerly during the north-east monsoon.

From February to April when the north-east monsoon is weakening, the current circulation of the Arabian Sea and Bay of Bengal has a special character differing from the two main monsoon periods. The south-west monsoon circulation obtains from May to September; October is a month of transition. From November to January, off the west coast of the Indian Peninsula, the predominant direction of the current to about 20° N. is north north-westerly; then north-westerly becoming west north-westerly along the Makkram coast. Off the Arabian coast it is south-westerly.

From February to April, the predominant flow in the open waters is westerly or north-westerly. About the end of January, the counterclockwise



TEXT-FIG. 2. Plan showing currents and prevailing winds. M = Mangalore; Ca = Calicut; Co = Cochin; and Q = Quilon. Winds shown thus ↙ (Arabian Sea) and thus ↙ (West coast). Currents shown thus →. Winds changing thus O. In Nov. O = Winds all round (Adapted from Bristow in Du Cane *et al.*, 1938).

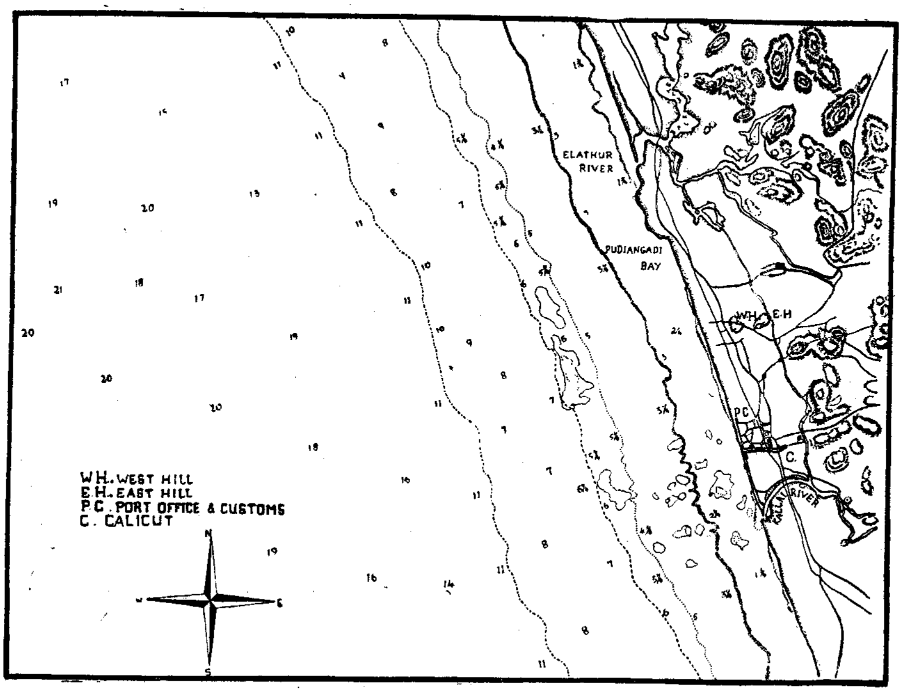
circulation of November to January ceases, and a coastal current in the opposite direction (clockwise) is gradually established; thus, the coastal circulation is reversed while the north-east monsoon is still blowing. The monsoon begins to wane from the beginning of March.

The reversal of the coastal current is simultaneous along all parts of the sea. This reversal, in the Arabian Sea, during the latter part of the north-east monsoon, is attributed to the formation of a gradient current, caused by temperature differences. By April, before the gradient current diminishes from diminishing temperature difference, the south-west monsoon begins and strengthens the clockwise coastal circulation as a normal current resulting from wind. This resulting coastal current is in continuity with the East African coastal current and this clockwise circulation obtains from May to September. Though there are often variations in the monsoonal drifts, the clockwise coastal circulation during the south-west monsoon is the most constant.

It may be mentioned here that an arm of the Cold Antarctic Flow surfaces in the Arabian Sea (Carpenter, 1887; Sewell, 1925, pp. 47–48) and further, the waters of the Antarctic Intermediate Currents, which rise from great depths towards the surface as they move along the East African coast, also enter the current circulation of the Arabian Sea (Mohamed, 1940, p. 193).

IV. Methods

Collections of plankton were obtained from four fixed stations in the Laccadive Sea off Calicut coast. These stations were situated from 2–12



Text-Fig. 3. Map of Calicut coast showing area of investigation. The numbers represent depth in fathoms (Adapted from Marine Survey of India Map. Figure by courtesy of Shri M. P. Laxman).

miles from the shore and the depth there varied from 4 fathoms (7·5 metres) to 20 fathoms (38 metres); station A at 8 fathoms, B at 4 fathoms, C at 10 fathoms and D at 20 fathoms (Text-Fig. 3). The last could not be worked during the height of the south-west monsoon season owing to inclement weather. It may be mentioned here that most of the commercial fishing along this coast is carried out within this area.

For a relative quantitative assessment of the fluctuation of the plankton, vertical hauls of plankton with a half-metre bolting silk (No. 16) net from a known depth to the surface, was used. This net was similar to the Harvey net (Harvey, 1934 *a*) in construction but with no meter attached. The employment of vertical hauls for quantitative work appears to be reliable (Gardiner, 1931; Russel and Coleman, 1931, 1934) and the values are roughly comparable to the true value of the standing crop (Hart, 1942, p. 277) and the estimate of the standing crop is more accurate than that made with a horizontal or an oblique net (Cushing, 1955, p. 11). Surface and oblique hauls with a ¾ metre net made of Organdie cloth have also been studied from the qualitative and taxonomical points of view.

Water samples were also collected from different stations and depths for a detailed and accurate assessment of the quantity of plankton; this also provided a reliable standard for comparison of the magnitude of the standing crop of different geographical regions where similar work had been done.

The quantity of phytoplankton was estimated by enumeration using a Sedgwick-Rafter counting cell and also by the extraction of the plant pigments with acetone according to Harvey's (1934 *a*) method. Other special techniques employed are mentioned in the appropriate sections.

It may be mentioned here that this appears to be the first time that such a quantitative assessment of the plankton, particularly phytoplankton, has been attempted in a tropical environment over a good length of time employing standard methods.

Simultaneously with the study of the plankton, the physical and chemical properties of the sea-water were also under observation. The results of these studies will be reported in a later account.

V. SEASONAL FLUCTUATION IN THE QUANTITY OF PHYTOPLANKTON

1. *Results of Enumeration*

With the signs of the oncoming south-west monsoon, the pre-monsoon thundershowers, the number of phytoplankton elements in the sea begin to increase (Table II). The peak of the bloom, judged by numbers, is attained

TABLE II

Station A. Total number of phytoplankton

Month \ Year	1949–50	1950–51	1951–52	1952–53	1953–54	1954–55	Average of 5 years
May ..	18,148,800	34,330,610	65,629,000	16,761,600	263,358,000	44,743,680	79,646,000
June ..	1,809,498,000	97,991,280	1,257,565,200	31,459,000	2,159,592,000	7,705,592,000	1,070,621,000
July ..	1,025,053,000	423,372,320	429,390,000	252,933,800	14,892,665,000	5,346,128,000	3,404,683,000
August ..	1,156,526,000	29,016,800	88,641,400	77,083,400	3,505,344,000	264,768,000	970,722,000
September	250,938,600	157,726,580	148,557,400	103,783,500	5,497,480	35,808,000	133,536,000
October ..	126,394,130	77,918,100	332,686,000	123,984,640	6,053,500	424,704,000	134,361,000
November	18,184,190	50,391,360	11,275,200	38,143,200	5,508,400	..	24,701,000
December	123,381,720	49,248,000	30,198,720	28,022,880	10,046,200	..	48,180,000
January ..	25,573,980	273,047,000	12,530,400	176,208,000	12,619,100	..	100,003,000
February	38,704,240	46,028,950	33,376,800	225,684,000	11,342,400	..	71,027,000
March ..	146,026,560	1,725,600	21,268,100	343,600,000	6,182,400	..	103,799,000
April ..	2,432,490	151,363,600	22,263,000	391,664,000	6,564,000	..	114,858,000

either in June (1949, 1951) or July (1950, 1952, 1953 and 1954) when the monsoon is most active. In some years, 1950 and 1952, the monsoon peak finds expression as a bifid one owing to the drop in the number of phytoplankton elements in August and a rise in September. As the season advances, the number of phytoplankton elements decreases somewhat, particularly the Diatoms, and those of the other elements increase a little; at the same time, there is a fall in the total number of plankton also.

During the period of maxima, the Diatoms constitute 97–99%, the Dinophyceæ 0·5–1·5%, the other phytoplankton elements (Silicoflagellateæ, Coccolithineæ, Cyanophyceæ, etc.) 0·5% and the zooplankton 0·4–0·8% of the total number of organisms in the plankton.* The bulk of the plankton at this time is quite obviously the phytoplankton with the Diatoms dominating the same.

By October–November, the north-east monsoon begins, most of this early period being a transition one. During this season also, the phytoplankton attains one (January 1951; April 1953; and January 1954) or two (December 1949 and March 1950; December 1951 and February 1952) peaks but of a lesser magnitude compared with those during the south-west monsoon season. During the period, at times other than those of peaks of phytoplankton development and generally during the season, the *bulk* of the plankton is contributed by the zooplankton elements. The composition in terms of number, however, is as follows: Diatoms, 92–97%; Dinophycæ, 1–5%; other algæ 0·3–0·8%; and zooplankton 1–1·5%. The elements other than the Diatoms show an increase over the previous season by 1½–6 times, 2–11 times and 2–4 times respectively taking the whole period of investigation under report into consideration.

The phytoplankton content during September to April, 1953–54, was very poor compared with the corresponding periods in the earlier years. This is probably due to the grazing effect on *Fragilaria oceanica* Cleve and other phytoplankton elements by the large shoals of the oil-sardine (*see below*). The fishery of the oil-sardine during that year was one of the best for over a quarter century (Nair and Subrahmanyan, 1955).

2. *Results of Plant Pigment Analyses*

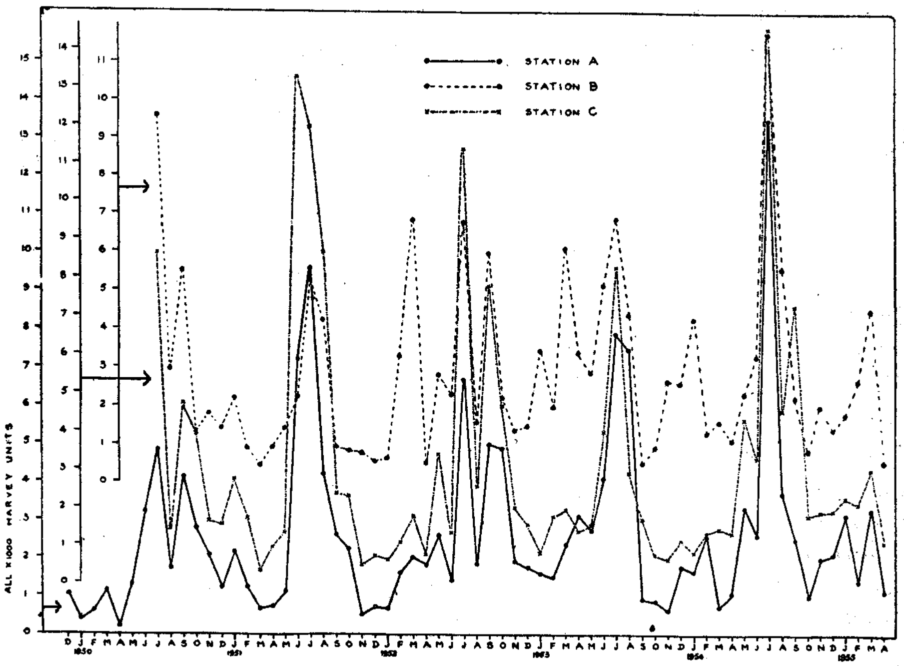
The fluctuation in the quantity of phytoplankton in terms of Plant Pigment Units or Harvey Units follows generally the pattern shown by their

* In the estimation of the number, the total number of cells have been reckoned; in the case of the colonial forms also the number of cells have been determined except in the case of the palmelloid Crysophyceæn alga, which, however, was not of common occurrence.

numbers; a direct proportional relationship could not, however, be established as the size of the cell and the pigment content of the floral constituents of the plankton vary considerably. The results are shown in Text-Fig. 4.

The main peak of development of phytoplankton occurs in July during the south-west monsoon season. In 1950 and 1952, the main peak may be said to be bifid, there being a fall in August and a rise in September, similarly noticed in the estimation in terms of number also. After August or September, the pigment value falls and later in the north-east monsoon period, the value oscillates and peaks of lesser magnitude occur. There is no constancy as to the time of occurrence of this secondary maximum; this may occur any time after the first principal peak between the following January and April. Secondary blooms were noticed in January 1951, March 1952, April 1953, February 1954 and January and March 1955 during the years of investigation.

During this season, the pigment extract, on some occasions, was not of its characteristic green colour and did not match well with the standards



TEXT-FIG. 4. Seasonal fluctuation in the quantity of phytoplankton in terms of Harvey Units (plant pigment units) at Stations A, B and C (Explanation in text).

unlike those during the earlier south-west monsoon season. This is very probably due to the contamination caused by the pigments of zooplankton elements, especially those of Copepods, which form the major portion of the zooplankton bulk during the season.

The trend of fluctuation during the course of several years (Text-Fig. 4) shows a rhythm in the seasonal production of phytoplankton in the water which is very striking when the peaks of production during the south-west monsoon season are considered. The main peaks of the alternate years, 1949, 1951 and 1953, are of a similar type. The bifid peaks in 1950 and 1952 resemble each other more than those of the earlier mentioned years. These resemblances are better brought out when the pigment values are considered than in terms of number. It is clear from the data on hand extending over five years that there is a variation in the intensity of the main peak of production of phytoplankton from year to year. A similar feature is evident in the plankton production between the Yorkshire coast and Dogger Bank (Wimpenny, 1944).

A study of the quantitative fluctuation of the different constituent elements of the plankton (unpublished) has shown that this variation is due to the blooming and dominance of different species of Diatoms during the period concerned, no two years being identical in this regard; further, the factors governing the blooming of the species themselves are internal and concern the life-history of the forms concerned. Some points about this aspect will be dealt with when dealing with the factors influencing phytoplankton production.

The enumeration method in quantitative studies is the most widely employed method and the oldest. The pigment extraction method is a more recent one and while this has been extensively employed in Europe and America, there are only a few similar accounts for the warmer waters of the world. Gilson (1937) appears to be the first to make use of this method in a warmer region; but his results, unfortunately, are not strictly comparable as they are based on samples taken at different stations during a cruise. Ramamurthy (1953 *b*) employed Harvey's method at Madras for the period 1951–52, but as he has not made use of a standard haul for collections (surface horizontal hauls have been used) his results are not comparable with the present investigation. Kow (1953) estimated successfully the phytoplankton of the Singapore Straits for two years (1948 and 1949—almost the same time when the present investigation was on here) in terms of Harvey Units. The results have similarity with those obtained by the writer. The seasonal fluctuation recorded by Kow in terms of numbers and pigment units are broadly comparable, there being peaks of abundance in April–May, July–August, October–November and sometimes in February. It seems to the writer that attempts at correlating the pigment content with the number of organisms is only of theoretical interest and not of any practical value as the composition of the flora exhibits unforeseeable variations which cannot be handled for relative assessment by two different methods.

Pigment values of known volume of the water sample (5 litres) have also been estimated during this period and these agree fully with the trend of the pigment values obtained based on samples by net collection (Table X).

VI. Quantitative Assessment of the Standing Crop of Phytoplankton and Zooplankton in a Unit Volume of Water Compared with Earlier Observations

1. *Phytoplankton*

An attempt at assessing the magnitude of the standing crop in terms of an internationally accepted standard can now be made to help comparison with the other regions from where such data are available. As the standing crop reflects the magnitude of production, a relative idea of the fertility of the different regions may thus be obtained.

For this purpose, the method adopted was as follows: From the region wherefrom net samples of plankton were collected, some large quantity of water was also collected from the surface, mid-depth and nearer the bottom. Equal known volumes of water from the three samples were filtered through a sieve of bolting silk of the same kind used in the plankton net. The plankton retained by the sieve was estimated by Harvey's method. A volume of the filtrate obtained after the above treatment was filtered through a No. 40 filter-paper and the sediment extracted by acetone to estimate the pigment content. By taking both values into consideration, the phytoplankton content in terms of Harvey Units in a metre cube of water was calculated, assessing the water samples from the three depths as a whole, equal volumes of which had been taken for filtration. Thus water from varying depths and distance from the shore has been analysed for sometime and the data recorded are given in Table X.

The results of the water sample analysis show that during the south-west monsoon season, the phytoplankton dominant period, the fluctuation in the quantity of phytoplankton varies from 11,000–2,48,000 Harvey Units per metre cube of water. During the north-east monsoon season, the range was between 4,000 and 50,000 Harvey Units per M^3 of water. The former period, obviously, has high phytoplankton content. The monthly average, during the south-west monsoon season, varied from 24,500 Harvey Units per M^3 of water in May to 92,800 Harvey Units per M^3 of water in July; during the north-east monsoon, the monthly average fluctuated between 12,714 Harvey Units per M^3 of water in November to 27,750 Harvey Units for the same quantity of water in January. It is seen that the standing crop is at its highest in July and gradually diminishes reaching the minimum in November, after which it increases somewhat, the quantity oscillating; in January, a small secondary peak may be distinguished; from then on the quantity fluctuates recording higher values gradually in alternate months. The results obtained by the analysis of water samples for plankton fully confirms those obtained by the employment of the net. The high phytoplankton content of the water obtained by the water sample method is striking compared with the lower values for net samples where, obviously, a large number of minute organisms escape through the meshes of the net. However, the net method is less tedious, more rapid and saves considerable time allowing at the same time a rapid relative assessment of the standing crop between stations or regions.

A back calculation taking into account the pigment values obtained by straining a known quantity of water through the silk sieve of the same kind used in the net, and the values obtained by vertical net hauls shows that the quantity of water filtered by the net varies from 24–460 litres (the extremes), the lower value (rare) obtaining during the season of high phytoplankton content and when the elements of the plankton are such as to cause clogging of the net. The average quantity of water strained by the net during a single haul works out to 120 litres of water. So, if the net values are multiplied by, say, 8⅓, we get approximately the value for one cubic metre of water strained. It may be mentioned that the volume of water passing through Harvey's metred net when hauled vertically from 50 metres to the surface is approximately only 1 metre cube of water (Harvey *et al.*, 1935). This would show that the figure arrived at by calculation for a vertical haul from 15 metres to the surface may generally be accepted for comparisons on a broad basis. Any error present is likely to be one of an underestimation only.

The mean variation (5 years' average) of phytoplankton content of net samples in Harvey Units is between 1,412 in November to 8,002 in July at Station A; 1,202 in October to 8,064 in July at Station B; and, 1,092 in April to 10,970 in July at Station C (Text-Fig. 4). In Table III, the calculated quantity of phytoplankton in terms of Harvey Units is shown for the net samples from Station A (the values from other stations are comparable).

TABLE III

Number of different groups of plankton organisms in 1 litre of sea-water and total quantity of phytoplankton in Harvey Units (based on the data from 5 years' average). Calculated values
Station A

Month		Diatomaceæ in 1 litre	Dinophyceæ in 1 litre	Miscellaneous Algae in 1 litre	Zooplankton in 1 litre	Phytoplankton in Harvey Units	
						In 1 M^3	Under 1 metre-sq. of sea surface
May	..	655,520	7,025	1,164	3,358	18,366	275,490
June	..	8,896,300	25,530	2,026	9,525	30,700	460,500
July	..	28,349,590	21,550	1,229	11,308	66,684	1,000,260
August	..	8,074,600	14,275	471	11,608	31,516	472,740
September	..	1,106,450	5,640	709	3,050	25,166	377,490
October	..	1,105,690	13,825	145	3,442	19,516	292,740
November	..	193,910	11,517	409	3,825	11,766	176,490
December	..	391,100	9,683	703	3,583	12,600	189,000
January	..	827,060	5,692	600	6,175	10,634	159,510
February	..	587,600	3,392	894	3,183	12,634	189,510
March	..	856,730	6,625	1,641	4,317	11,416	171,240
April	..	945,050	10,000	2,103	5,083	11,416	171,240

TABLE

Comparison of the magnitude

[Figures in thousand ; figures within brackets

Area	Year	January	February	March	April
1 South-west coast of India Net plankton at 15 metres depth off Calicut shore (Calculated values)	1949–55 (Average of 5 years observations)	159 (20)	189 (20)	171 (20)	171 (20)
2 do. water samples off area at 15 metre depth	1955–56	413 (8)	253 (8)	365 (9)	297 (9)
3 Gulf of Maine ..	1939	..	..	..	..
	1940	85 (1)	..	310 (1)	620 (1)
	1941	..	820 (1)	820 (1)	690 (1)
4 Georges Bank ..	1939	..	..	..	..
	1940	110 (8)	..	1040 (13)	2250 (15)
	1941	..	..	350 (29)	1390 (31)
5 Coastal water ..	1939	..	..	..	..
6 Cape Cod-Montauk Point ..	1947	..	..	460 (3)	..
7 Slope water ..	1939	..	..	..	..
	1940	250 (2)	..	470 (1)	3800 (1)
	1941	..	..	890 (1)	3540 (2)
	1947	..	..	370 (1)	..
8 Sargasso Sea :					
North-west Bermuda ..	1939	..	..	..	..
	1947	..	..	..	..
Bermuda to Azores ..	1947	..	..	..	..
	1948	..	..	..	..
9 Gulf Stream System :					
Florida Straits ..	1937	..	..	..	..
	1939	..	..	..	..
Carolinas ..	1939	..	..	..	..
Off Montauk Point ..	1939	..	..	..	..

IV

of the standing crop

indicate number of observations]

May	June	July	August	September	October	November	December
275 (20)	460 (15)	1000 (12)	472 (20)	377 (20)	292 (20)	176 (20)	189 (20)
367 (6)	900 (4)	1392 (6)	1373 (10)	835 (8)	589 (8)	191 (7)	222 (10)
..	..	..	..	560 (2)	..	..	..
..	..	..	..	..	..	..	..
1230 (2)	490 (2)	..	..	..	..	..	..
..	..	..	..	560 (22)	..	..	..
860 (20)	500 (28)	..	..	..	..	..	..
1280 (29)	330 (29)	..	..	..	..	..	..
90 (2)	..	..	..	..	..	..	..
..	..	..	..	..	..	..	200 (3)
220 (2)	..	..	..	380 (2)	..	..	..
1180 (1)	250 (2)	..	..	..	..	..	..
270 (2)	340 (1)	..	..	..	..	..	..
..	..	..	..	..	..	..	300 (1)
310 (5)	..	..	..	..	..	..	..
..	..	..	..	..	..	..	410 (2)
..	..	..	50 (5)	..	..	..	420 (7)
..	100 (3)	..	..	..	..	..	..
..	..	..	100 (1)	..	..	..	..
480 (5)	..	..	..	..	..	..	..
370 (2)	..	..	..	..	..	..	..
300 (1)	..	..	..	..	..	..	..

TABLE V

Comparison of the magnitude of the standing crop

Region or Area	English Channel* 0–15 metres ?	*Antarctic waters (Hart 1942*) — Northern	Intermediate	Southern	South Georgia	Scotia Sea	Georges Bank (Riley, 1941)
Period ..	1st March to 3rd July 1934	27th September to 1st February, 1938–39	27th November to 8th March	20th January to 4th March	13th October to 27th January	6th October to 15th February	March to June
Number of observations	16	61	87	42	72	55	24
Mean Units per metre-cube of sea-water	1,000	1,210	1,100	1,150	11,690	2,390	11,670 (Average of observations at different depths)
Highest individual observation	3,850	7,540	9,420	12,050	60,040	21,040	65,000

Region or area	North central part of Long Island Sound — 20 metres or less (Riley, 1952)				Calicut 0–15 metres — Net sample	Water sample	Singapore (Kow, 1953)	Block Island sound (Riley, 1952)
Period ..	September 7th 1938 to August 18th, 1939	July 8th to November 13th, 1940	June 16th to September 22nd, 1941	March 17th to July 26th, 1950	June to October (5 years data-average)	July to October, 1955	1948 and 1949	January and December
Number of observations	65	54	51	9	About 100 (20 in all for each month	32	..	..
Mean Units per metre-cube of sea-water	*ca*55,600	45,200	45,600	31,500	32,000†	66,900	1500 and 2500 respectively	11,200
Highest individual observation	194,000	125,000	79,000	75,000	147,300†	248,000	..	26,000

* Data from Hart, 1942 † Calculated values.

TABLE VI

Total number of phytoplankton in a litre of sea-water

Month	Aomori Bay (Kokubo, 1932)		Woods Hole (Lillick, 1937)	Calicut, net samples Average of 5 years, calculated	Calicut, water sample centrifuged
	1929	1930			
January ..	6,460	780	182,000	833,460	..
February ..	19,430	560	19,200	591,900	..
March ..	15,280	40,300	1,200	865,000	..
April ..	5,960	46,470	20,900	957,200	..
May ..	6,230	39,230	12,000	663,700	..
June ..	10,940	14,320	32,400	8,921,800	..
July ..	21,780	13,400	111,800 10,400	28,372,400	18,081,600
August ..	4,640	87,600	143,100 12,400	8,089,350	4,120,700
September ..	64,270	10,800	12,800	1,112,800	1,921,500
October ..	5,140	85,800	305,000	1,119,700	9,604,800
November ..	2,280	55,780	60,300	205,800	..
December ..	12,290	29,300	13,000	401,500	..

TABLE VII

Total number of Diatom cells in one litre of sea-water

Month		Calicut Average of 1949–54	Low Isles* Series 1 1928–29	Plymouth* 1915–16	Loch Striven* 1926	Kiel Bay* 1905–06	La Jolla* 1922	Calicut 1954 Water sample centrifuged
January	..	827,060	4,750	2,190	7,000	4,100	5,920	..
February	..	587,600	2,070	1,620	34,000	4,800	19,170	..
March	..	856,730	5,180	2,070	1,356,000	48,000	13,310	..
April	..	945,050	5,440	38,560	3,792,200	850,000	312,510	..
May	..	655,520	5,470	30,420	1,686,900	2,100,000	11,770	..
June	..	8,896,300	6,390	9,120	585,500	2,480,000	23,220	..
July	..	28,349,590	5,780	21,390	620,900	37,000	2,650	18,071,000
August	..	8,074,600	17,810	31,780	2,774,900	130,000 (44,000)	590	4,085,600
September	..	1,106,450	5,310	17,110 (2,990)	693,650	1,400,000	2,880	1,918,000
October	..	1,105,690	2,990	17,410	179,000	440,000	2,530	9,572,850
November	..	193,910	5,040	9,500	196,000	15,000	85,290	..
December	..	391,100	3,280	1,500	186,000	8,500	110	..

* Data from Marshall, 1933.

Total number of phytoplankton beneath 0·1 metre-square of the sea

Month	Gulf of Maine (Bigelow, Lillick and Sears, 1940)				Calicut (Net samples)		Calicut (Water sample) (Single observations)
	Mean	Maximum	Minimum	Mean (based on 5 years data)	Maximum	Minimum	
January ..	6,026,000	12,073,000	1,672,000	1,250,190,000	7,877,000,000	10,665,000	..
February ..	..	..	..	887,850,000	5,356,000,000	1,413,000	..
March ..	29,487,000	117,425,000	550,000	1,297,500,000	18,420,000,000	930,000	..
April* ..	1,759,767,000	13,965,600,000	80 000	,435,800,000	13,044,000,000	870,000	..
May† ..	55,347,000	142,100,000	50,000	995,550,000	12,837,600,000	346,500	..
June ..	6,650,000	27,310,000	1,120,000	13,382,700,000	267,183,000,000	12,388,000	..
July‡ ..	21,685,000	198,080,000	800,000	42,553,600,000	667,248,250,000	230,400,000	27,122,400,000
August ..	..	..	..	12,134,250,000	124,236,000,000	32,875,000	6,181,050,000
September ..	37,660,000	283,012,000	2,013,000	1,669,200,000	6,096,600,000	6,600,000	2,882,250,000
October ..	7,856,000	18,161,000	649,000	1,679,550,000	19,838,400,000	12,240,000	14,407,200,000
November ..	..	..	..	308,700,000	1,868,832,000	481,500	..
December ..	1,852,000	3,230,300	80,000	602,250,000	3,257,970,000	2,310,000	..

*, †, ‡: Gulf of Maine data for April-May, May-June and June-July.

Data From Lohman, 1920.* (Mean values for water column)

Month	Atlantic 40–50° N. and 10–30° W.	Atlantic 40–30° N.	Atlantic 30–20° N.	Atlantic 20–10° N.	Atlantic 10–0° N.
May ..	240,000,000	80,000,000	24,000,000	20,000,000	24,000,000
June ..	240,000,000	80,000,000	24,000,000	20,000,000	24,000,000
? ..	..	..	..	75,000,000†	46,000,000†

* Data as given by Riley *et al.* (1949). † Hentschel's (1932) data as given in Riley *et al.* (1949).

TABLE IX

Total number of Dinophyceæ cells in one litre of sea water

Month	Calicut Average of 1949–54	Low Isles* Series 1 1928–29	Plymouth* 1915–16	Loch Striven* 1926	Kiel Bay* 1905–06	La Jolla* 1922	Calicut 1954 Water sample centrifuged
January ..	5,692	960	3	400	7,000	460	..
February ..	3,392	780	2	300	4,800	360	..
March ..	6,625	450	20	1,800	16,000	820	..
April ..	10,000	350	30	6,940	18,000	4,770	..
May ..	7,025	680	120	6,250	31,000	5,140	..
June ..	23,530	860	1,020	8,240	187,500	2,230	..
July ..	21,550	1,060	120	3,960	382,000	600	10,600
August ..	14,275	1,470	730	10,000	146,000 (105,000)	470	35,080
September ..	5,640	1,020	120 (640)	6,400	19,000	790	3,550
October ..	13,840	970	80	7,700	6,600	1,040	31,990
November ..	11,518	860	20	3,430	14,000	1,130	..
December ..	9,683	1,110	8	1,600	7,400	600	..

* Data from Marshall, 1933.

TABLE X

Standing crop of phytoplankton as estimated from water samples by Harvey method and in terms of carbon per square metre of sea surface

Date	Sampling station-depth in metres	Number of Harvey Units per metre-cube of water	Number of Harvey Units under one metre-square of sea	Number of grams carbon under one metre-square of sea	Monthly average H.U./M³
4– 7–1955	15	160,000	2,400,000	7·920	
7– 7–1955	19	20,000	380,000	1·254	
7– 7–1955	0	(4,000)	76,000	0·251	
8– 7–1955	11·25	15,000	168,750	0·557	
11– 7–1955	19	20,000	380,000	1·254	
22– 7–1955	3·75 (Quilandy).	80,000	300,000	0·990	
28– 7–1955	15	248,000	3,720,000	12·280	92,800
1– 8–1955	15	110,000	1,650,000	5·445	
4– 8–1955	19	28,000	532,000	1·756	
8– 8–1955	19	100,000	1,900,000	9·017	
10– 8–1955	22·5	47,000	1,057,500	3·489	
11– 8–1955	33·75	24,000	810,000	2·673	
16– 8–1955	19	76,000	1,444,000	4·765	
17– 8–1955	11·25	216,000	2,430,000	8·166	
18– 8–1955	33·75	32,000	1,080,000	3·565	
22– 8–1955	19	172,000	3,268,000	10·780	
25– 8–1955	33·75	110,000	3,712,000	12·260	91,500
1– 9–1955	28	80,000	2,240,000	7·392	
5– 9–1955	19	55,000	1,045,000	3·449	

TABLE X (*Contd.*)

Date	Sampling station-depth in metres	Number of Harvey Units per metre-cube of water	Number of Harvey Units under one metre-square of sea	Number of grams carbon under one metre-square of sea	Monthly average H.U./M³
8- 9-1955	30	90,000	2,700,000	8·910	
12- 9-1955	19	80,000	1,520,000	5·017	
15- 9-1955	33·75	43,000	1,451,000	4·788	
20- 9-1955	19	68,000	1,292,000	4·264	
22- 9-1955	33·75	13,500	455,500	1·503	
26- 9-1955	19	16,000	304,000	1·003	55,688
3-10-1955	19	23,000	437,000	1·442	
6-10-1955	33·75	40,000	1,350,000	4·454	
10-10-1955	19	65,000	1,235,000	4·076	
13-10-1955	33·75	46,000	1,552,000	4·069	
17-10-1955	19	34,000	646,000	2·132	
20-10-1955	22·5	41,000	922,600	3·832	
27-10-1955	19	21,000	399,000	1·317	
31-10-1955	19	44,000	836,000	2·759	39,250
3-11-1955	32	7,000	224,000	0·739	
7-11-1955	19	27,000	513,000	1·693	
10-11-1955	32	13,000	416,000	1·373	
17-11-1955	19	10,000	190,000	0·627	
21-11-1955	19	4,000	76,000	0·0627	
24-11-1955	34	16,000	544,000	2·061	
28-11-1955	19	12,000	228,000	0·7525	12,714

TABLE X (*Contd.*)

Date	Sampling station-depth in metres	Number of Harvey Units per metre-cube of water	Number of Harvey Units under one metre-square of sea	Number of grams carbon under one metre-square of sea	Monthly average H.U./M³
1–12–1955	34	4,000	136,000	0·4488	
5–12–1955	19	14,000	266,000	0·8778	
8–12–1955	38	24,000	912,000	3·005	
12–12–1955	19	16,000	304,000	1·003	
13–12–1955	11	18,000	198,000	0·6534	
15–12–1955	38	10,000	380,000	1·254	
19–12–1955	19	8,000	152,000	0·5017	
22–12–1955	38	13,000	494,000	1·630	
26–12–1955	19	23,000	437,000	1·442	
29–12–1955	38	18,000	684,000	2·257	14,800
2– 1–1956	19	45,000	855,000	2·821	
5– 1–1956	34	11,400	387,600	1·279	
9– 1–1956	19	36,000	684,000	2·257	
12– 1–1956	38	4,000	72,000	0·5017	
16– 1–1956	19	18,000	342,000	1·129	
19– 1–1956	38	8,000	304,000	1·0034	
23– 1–1956	19	48,000	912,000	3·009	
30– 1–1956	19	50,000	950,000	3·135	27,550
2– 2–1956	32	3,000	96,000	0·3135	
6– 2–1956	19	29,000	551,000	1·8190	
9– 2–1956	34	11,000	374,000	1·234	
13– 2–1956	19	18,000	342,000	1·219	
16– 2–1956	34	18,000	612,000	2·019	
20– 2–1956	19	25,000	475,000	1·568	
23– 2–1956	38	4,000	72,000	0·5017	
27– 2–1956	19	27,000	513,000	1·693	16,875
1– 3–1956	34	16,500	561,000	1·851	

TABLE X (*Contd.*)

Date	Sampling station-depth in metres	Number of Harvey Units per metre-cube of water	Number of Harvey Units under one metre-square of sea	Number of grams carbon under one metre-square of sea	Monthly average H.U./M^3
5- 3-1956	19	47,000	893,000	2·947	
8- 3-1956	38	28,000	1,064,000	3·512	
12- 3-1956	19	38,000	722,000	2·383	
15- 3-1956	34	32,500	1,105,000	3·647	
19- 3-1956	19	27,000	513,000	1·693	
22- 3-1956	34	14,000	476,000	1·570	
26- 3-1956	19	13,000	247,000	0·8151	
29- 3-1956	38	4,000	132,000	0·5017	24,556
2- 4-1956	19	13,500	256,500	0·8465	
5- 4-1956	32	32,000	1,024,000	3·378	
9- 4-1956	19	37,000	703,000	2·320	
12- 4-1956	32	20,000	640,000	2·112	
16- 4-1956	19	10,000	190,000	0·627	
19- 4-1956	34	18,000	612,000	2·019	
23- 4-1956	19	19,000	361,000	1–191	
26- 4-1956	30	13,000	390,000	1·286	
30- 4-1956	19	16,000	304,000	1·003	19,833
3- 5-1956	30	11,000	330,000	1·089	
7- 5-1956	19	23,000	437,000	1·442	
10- 5-1956	34	11,000	374,000	1·234	
14- 5-1956	19	19,000	361,000	1·191	
29- 5-1956	15	36,000	540,000	1·782	
31- 5-1956	6	47,000	282,000	0·9307	24,500
4- 6-1956	11	17,000	187,000	0·6175	
11- 6-1956	11	63,000	693,000	2·287	
14- 6-1956	11	102,000	1,122,000	3·702	
18- 6-1956	15	58,000	870,000	2·871	60,000

TABLE XI

Comparison of plankton abundance in various areas of the world

Area	Plankton values Number/volume in c.c.	Mesh apperture of net used	Reference	Remarks
IFIC AREA—				
moa to the Marshalls the Equator	0·4 to 0·95 c.c./m³	0·33 mm.	Krämer (1906)	
a Sea ..	Avg. = 0·83 c.c./m³	0·33 mm.	Delsman (1939)	
n Sea Palau Is. ..	110 to 530 no./m³	0·33 mm.	Motoda (1940)	
ini, just outside reef ..	26·23 to 62·20 no./m³	0·37 mm.	Johnson (1949)	
t coast, U.S. ffshore stations)	0·016 to 0·129 c.c./m³ Avg. = 0·057 c.c./m³	0·65 mm.	California Prog. Rept. (1950)	
tral Pacific ..	5 to 109 no./m³, Avg. = 35; 0·002 to 0·102 c.c./m³ Avg. = 0·027 c.c./m³	0·65 mm.	This report (King and Demond, 1953)	
ANTIC AREA—				
tic Sea ..	1·9 to 11·0 c.c./m³	0·33 mm.	Krämer (1906)	
f of Maine (10 to 0 metres depth)	0·12 to 4·30 c.c./m³	1·25 mm. front; 0·8 mm., middle and rear	Bigelow (1926)	
rth Atlantic (Coastal ater)	Avg. = 0·5 to 0·8 c.c./m³	29·38 meshes/in., front; 48·54 meshes/in. rear	Bigelow and Sears (1939)	
rida Strait ..	0·02 c.c./m³	0·158 mm.	Riley (1939)	
f Stream, off Florida ..	0·05 c.c./m³			
f Stream, off Georgia ..	0·07 c.c./m³			
rth Atlantic continental ope	4·3 c.c./m³			
th Atlantic, coastal ..	8·1 c.c./m³			
rth Atlantic, coastal ..	Avg. = 0·54 c.c./m³ Max. = 15·5 c.c./m³	10 strands/cm.	Clarke (1940)	
rth Atlantic, offshore ..	Avg. = 0·40 c.c./m³ Max. = 3·50 c.c./m³			
gasso Sea ..	Avg. = 0·045 g./m³	0·158 mm.	Riley and Gorgy (1948)	
f Stream ..	1 sta. = 0·137 g./m³			
pe water ..	2 sta. = 0·14 and 1·6 g./m³			
HER DATA—				
ar Equator ..	0·5 to 5 c.c./ ?	?	Tokioka (1942 *a*)	Vertical haul from 50 to 0 m.
° N. latitude ..	0·25 to 1·75 c.c./ ?	?	Haneda (1942)	
waiian waters ..	20·0 to 40·0 c.c.	0·65 mm.	King and Hida (1954)	Oblique tow from 200 to 0 m.
ock Island Sound ..	Less than 2 c.c./m³	No. 10 net	Deevy (1952 *b*)	
glish Channel ..	0·1 to 4 c.c./m³	?	Harvey *et al.* (1935)	
w South Wales coast ..	Avg. 7·6 c.c. Var. 1–28 c.c. in 1943; Avg. 11·7 c.c. Var. 2–41 c.c. in 1944	?	Sheard (1949)	
th-east coast of India	Up to 40 c.c.; avg. much less	Organdy net, *ca.* 36 str./cm.	Prasad (1954 *a*, 1956)	Oblique hauls *ca.* 10 to 0 m.
est coast of India Calicut	11·75 to 32·5 c.c.	do.	George (1953 *a*)	Oblique hauls *ca.* 15 to 0 m.
do.	20 c.c./m³ max.	No. 16 net	Present account	Vertical hauls from 15 to 0 m.

* From King and Demond (1953).

† By writer.

TABLE XII

Zooplankton in 100 litres of water (comparison with other data)

Months	Calicut, net samples; 5 years average calculated for 100 litres	Calicut, water samples centrifuged material	Plymouth Station L_4, 1934 Harvey *et al.*, 1935	Kiel Bay; Lohman, 1908	
January ..	444,600	..	239	3,700	1906
February ..	229,200	..	545	4,700	
March ..	310,800	..	2,024	6,000	
April ..	366,000	..	2,518	5,800	
May ..	241,800	..	3,365	28,000	
June ..	685,800	..	2,440	7,400	
July ..	814,200	3,730,000	2,852	37,000	
August ..	835,800	4,798,600	4,943	7,600 19,000	1905
September ..	219,600	2,220,000	4,818	24,000	
October ..	247,800	2,308,000	1,839	24,000	
November ..	275,400	..	1,338	13,000	
December ..	258,000	..	736	5,700	

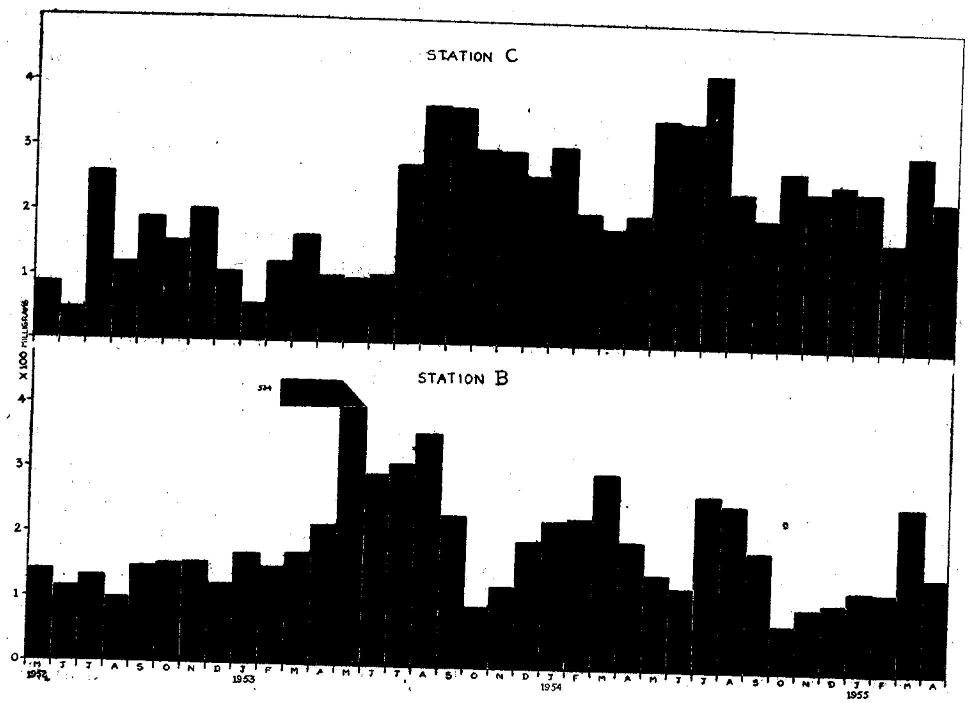
urface, the depth of the sampling stations not exceeding 40 metres. Highest alues occur during the south-west monsoon season.

It may be mentioned in this connexion, that a very rich catch of plankton 1 the English Channel (Harvey, 1945, p. 143) showed 1·5 grams of carbon eneath one metre square of sea surface. In the Gulf of Maine, during the ichest period, one metre-square of sea surface contained 2 grams of carbon Riley, 1941). In the Antarctic (which is one of the most fertile seas of the vorld) 7·2 grams of carbon for a similar water column has been calculated Hart, 1942). The richest catch on the west coast of India for a water olumn of 15 metres depth represented 12·28 grams of carbon per metre-quare. It may be reliably stated that the west coast of India is one of the ighly productive regions of the world in general and the tropics in particular. This is borne out by all aspects of study—enumeration of plankton content, stimation of plant pigments and of carbon content. Further, it is seen hat throughout the year there is a high standing crop, the intensity of which hows clear seasonal fluctuation.

VIII. Seasonal Fluctuation in the Quantity of Total Plankton—Dry Weight

The dry weight was estimated as follows: the whole sample of plankton vertical haul) was filtered through a No. 40 Whatman filter-paper, dried at 0° C. to constant weight. The method employed for collection and for rying, etc., are almost similar to that employed by Graham (1941 *a*). In his method both phyto- and zoo-plankton are included.

In Text-Fig. 5 is shown the fluctuation of the total plankton content f the catch in terms of dry weight, on the basis of monthly average for a eriod of three years, at Stations B and C. It may be seen that only on a ery few occasions has the quantity per haul fallen below 100 milligrams. At Station B, the monthly overall average for the three years was 148, 259 nd 160 milligrams and at Station C, 135, 239 and 275 milligrams respectively or the three years 1952–53, 1953–54 and 1954–55. Such sharp oscillations seen n terms of number and of Harvey Units is absent in this instance and there s also not much difference in the dry weight of plankton during the two main easons, though the *bulk* of the plankton is phytoplankton during the south-west monsoon period and zooplankton during the north-east monsoon eason. Two interesting points stand out here, namely, that in those years when the plankton bulk is poor during the south-west monsoon season, here is a fall during the north-east monsoon season also; secondly, the ratio of the quantity of plankton in terms of dry weight, that of the south-west monsoon season to that of the north-east monsoon season (totals of May to October and November to April respectively) shows a striking relationship, the values being 1 : 1·2, 1 : 0·7, 1 : 0·8 at Station B and 1 : 0·9, 1 : 1, 1 : 0·8 at Station C for the years 1952–53, 1953–54 and 1954–55 respectively. The overall average of the three years at Stations B and C is the same, *viz.*, 1 : 0·9. Perhaps the slight difference noticed might represent unsampled forms of life in the sea. This relationship is probably an indication that the water column at a particular period (six-month season) is able only to support a more or less fixed amount of life, *biomass* (whether floral or faunal matter) which is somewhat analogous to the equilibrium of some of the constituent elements in the sea-water, *e.g.*, Nitrogen, Silicon and Phosphorus (Sverdrup *et al.*, 1942; Subrahmanyan, Part II). This relationhsip is worth investigating at other centres also.



TEXT-FIG. 5. Seasonal fluctuation in the quantity of plankton in terms of dry weight at Stations B and C (Explanation in text).

Graham (1941 *a*) studied the plankton in the Pacific between 40° N. and 20° S. latitude during a cruise on the *Carniegie*. He showed that there was greater production of plankton in the tropics than in the more northern latitudes. Apart from the fact that the production on the west coast of India is even higher than at the Pacific stations, the striking similarity of the results obtained from these two investigations is worth noting; however, there is one difference in that the main constituents of Graham's collections appear to be zooplankton, whereas here the collections are of a mixed type. Nevertheless, in view of the close approximation in the ratio of the dry weights between the predominantly phytoplankton period and the later zooplankton period, the present results are definitely comparable with those from the Pacific.

Riley and Gorgy (1948) recorded an average plankton content of 45 milligrams per M^3 of water in the Sargasso Sea, 137 milligrams per M^3 in the Gulf Stream and 140 and 1,600 milligrams at two stations respectively on slope water. All vertical hauls have an average monthly value exceeding 1,000 milligrams per metre cube of water at both Stations, B and C, during all the years of the present investigation. This indicates a very high standing crop for the west coast of India and thus a high fertility for the area.

In a critical review of the utility of the pigment values in quantitative determination of phytoplankton, Margalef (1954) states that the quantity of pigment in the cells is influenced by various factors and, therefore, he believes, that the pigment value alone is not a sound index whether of the standing crop or of productivity, but that the same together with dry weight estimations is able to show most interesting features of the dynamics of production. Estimations of plankton by dry weight in the present investigation have similarly revealed some interesting facts about production of matter in the sea not brought out either by the pigment extraction method or enumeration method.

IX. Horizontal Distribution of Phytoplankton

As already mentioned, samples of plankton from four stations A, B, C and D, varying in distance from the shore, have been studied; for the first three, data are available for over five years; but, for D the data is considerably interrupted as this station could not be worked during the southwest monsoon season owing to inclement weather. Only pigment values have been taken into consideration. The enumeration data are complete only for Station A; as the results of two years' enumeration for B and C showed more or less the same trend in the fluctuation as at A, this method was discontinued.

Text-Figure 4 shows the fluctuation in the quantity of the standing crop of phytoplankton at these stations. It may be seen that, in general, the trend of fluctuation is the same at all stations, that at A and C, stations farther out, being closely identical. At Station B also the trend in the fluctuation of the quantity of phytoplankton is similar except for some minor differences.

At Station B, in 1951–52, the north-east monsoon bloom in March was of a higher order than the south-west monsoon bloom in July. In 1952–53, the north-east monsoon peak was bifid, there being a small peak of production in January and an intense one in March. It may also be noticed that closer the station is to the shore, greater the frequency in the number of oscillations in the quantity of the standing crop. This is probably due to the inshore environment where wind plays a rôle in the mixing up of the water layers more thoroughly than at stations farther off-shore and the consequent increase of certain nutrients from the bottom mud enabling an increased multiplication of the floral elements. A similar feature brought about by wind action has been noticed by Marshall (1933) in the Great Barrier Reef region.

Further, certain differences in the intensity of the bloom of phytoplankton at these stations (as far as it could be judged though there was no means by which the quantity of water strained through the net could be measured directly) were met with frequently. During the south-west monsoon season, at the beginning, the bloom of phytoplankton is of a high order at stations farther away from the shore than at places nearer; later, when the weather conditions become stabilised, the bloom over the whole area is more or less of the same intensity, and the flora also is similar. The differences early in the season may be due to the very low salinity of the shore water. Too low a salinity appears to be injurious to the floral elements.

While there appears to be some uniformity in the composition of the flora during the south-west monsoon season, often striking differences are noticeable during the north-east monsoon in the constituent elements from the different stations. These differences may be due to the fact that currents are unsettled during the early part of the season (October to December) leading to patchy distribution of the plankton organisms. Later in the season, when conditions become more stable and the main south-to-north current establishes itself bringing water from the Bay of Bengal also, the differences noticed earlier tend to disappear. The secondary maxima may also be due to the effect of the influx of new water into the Arabian Sea in this current.

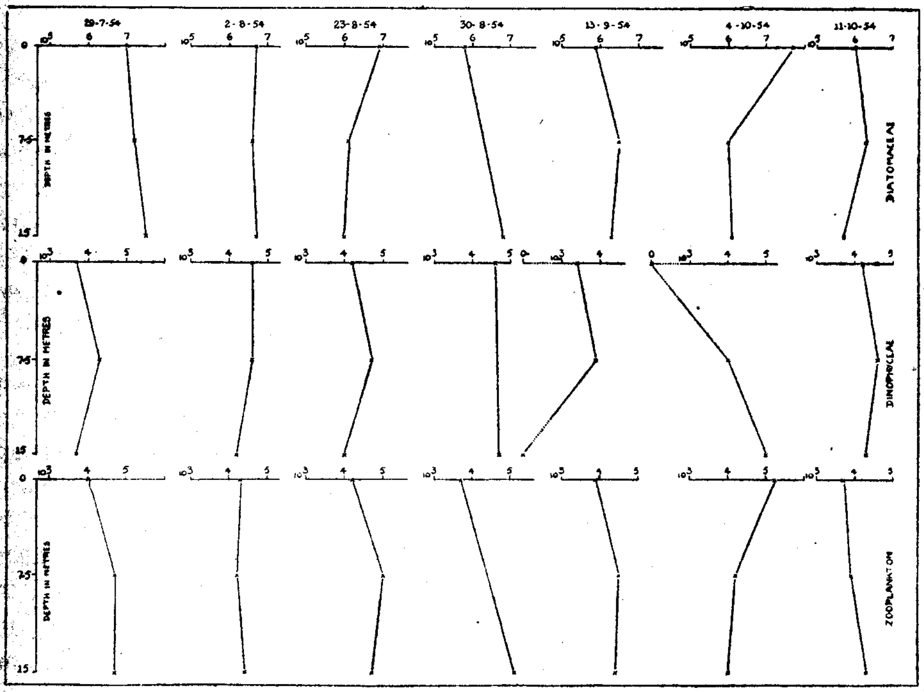
Samples of plankton obtained from Quilandy Bay, 17 miles north of Calicut, was found to be very similar and comparable in general to those of Calicut, as also a few samples examined from Karwar* farther north and Vizhingam* far south. It would appear that the microvegetation of the sea

* Through the courtesy of Mr. S. Ramamurthy and Dr. V. Balakrishnan respectively.

during the south-west monsoon period is more or less uniform in composition over a great extent of the west coast of the Indian Peninsula. There may be some difference as to the time of outburst of the flora depending on the advance of the monsoon from south to north.

X. Vertical Distribution of the Plankton Elements

No detailed work on this aspect could be undertaken; however, some analyses of water samples from known depths taken in a vertical plane (surface, mid-depth and bottom) were carried out and the distribution shown by the Diatomaceæ, Dinophyceæ and the Zooplankton is shown in Text-Fig. 6. Most of the samples relate to the south-west monsoon period.



Text-Fig. 6. Vertical distribution of Diatomaceæ (Bacillariophyceæ), Dinophyceæ and Zooplankton in the water (Explanation in text).

During this period, the Diatoms appear to show a preference to the bottom layers, probably due to the very low salinity obtaining at times at the surface owing to heavy rainfall, either as a reaction to it or to the fall in the specific gravity of the water or both. In the following season, north-east monsoon period, they show a tendency to be distributed in the upper layers. The Dinophyceæ generally seem to prefer the middle layers. It is also known that the vertical distribution of the Diatomaceæ and Dinophyceæ may be related to their reaction to varying light intensities (Harvey, 1939; Steemann Nielsen, 1939; *cf.* also Phifer, 1934).

The zooplankton is confined to the mid-depths and bottom layers presumably due to their well-known characteristic reaction to light intensity (Russel, 1925, 1926, 1927, 1934 *a*, 1936 *c*; Clarke, 1933; Hardy, 1951; Hardy and Bainbridge, 1954; and Wiborg, 1955). No collections were made after sunset; the above results are based on collections made in the forenoon.

XI. SEASONAL FLUCTUATION IN THE QUANTITY OF THE MAIN CLASSES OF ORGANISMS IN THE PLANKTON

1. *General Remarks*

For studying the fluctuation of the different classes of organisms and of individual species only enumeration data are useful. The Diatoms dominate the flora, followed by the Dinophyceæ and some minor classes of algæ. Under the last, Cyanophyceæ, Silicoflagellatæ, Coccolithineæ and Chrysophyceæ are all included as, either together or separately, they do not contribute to the bulk of the plankton except the Cyanophycean elements, species of *Trichodesmium*, on some occasions during the warmer months, February to April.

The number of species of phytoplankton occurring at a time in any one collection varies from 12–74 and the majority of them are of the Diatoms. The Dinophyceæ constitute the bulk when *Noctiluca miliaris* Sur. happens to occur in large numbers. Nearly 360 species of microscopic plants occur in the plankton on the west coast of India (Subrahmanyan, 1958). The pattern of the flora keeps on changing at varying intervals as also the numbers of the different species. Greatest variety is seen when the plankton content is also higher, but only a few species go to make up the bulk of the flora during the peak periods, sometimes one alone. Further, it is not the same species that contributes to the bulk in all the years or in any two of the years nor is there any constancy in the species contributing to the peaks during the year. A cursory analysis indicates a possible association of certain species during their occurrence similar to the associations seen in the case of land plants and larger benthic sea-weed vegetation. It is likely that there is a sort of mutual antagonism owing to excretion of external metabolites or a conditioning of the medium (Lucas, 1947, 1949, 1955; Rice, 1954) the resultant flora depending on the mutual interaction of the excretions and the degree of tolerance of the organisms to them. The occurrence of different species in succession also suggests, as mentioned by McCombie (1953, p. 279) in connexion with the lakes of North America, that there is a cyclical succession of pulses of different phytoplankton species throughout the years.

It may be mentioned here, that generally in the inland waters, the phytoplankton organisms inhabiting them—Volvocales, Desmids, and so on, and even some Diatoms—have more or less an annual life-cycle, a period of vegetative phase and then sexual reproduction at the end of which the zygotes formed hibernate for tiding over unfavourable periods such as drought in the warmer parts of the world and severe winter conditions in the temperate and cold regions. The Diatoms—the major constituent of the phytoplankton in all the seas—however, have a life-cycle known to extend over one or more years, even up to 15 years (Hustedt, 1930), but generally a two-to-four-year cycle may be the most usual (Wimpenny, 1936 *b*; 1946, 1956; writer, unpublished). It is proposed to give details of the succession of the species and their peaks, etc., in another paper of this series; however, one instance may be mentioned here, *viz.*, that of *Fragilaria oceanica* Cl. as its fluctuation is referred to in another section. This Diatom, like any other species, multiplies by vegetative division, the cells getting diminished in size after each such division as is characteristic of Diatoms. When the minimum characteristic size (Iyengar and Subrahmanyan, 1944; Subrahmanyan, 1947) for the species is attained, the cells form auxospores, preceded by a sexual process; and, after this, the zygote grows into a large cell (a period of hibernation is not so far known in Diatoms) and thus the characteristic upper limit for the species is attained. This process of auxospore-formation gives the stimulus for renewed rapid multiplication, the rate of which gradually diminishes as the population ages. In the present instance, of *Fragilaria*, it has been inferred from the presence in large numbers of chains composed of large cells approximately every four years or so, that the Diatom has a four-year life-cycle and attains its highest peak of development during those years of auxospore-formation.

The variations in the intensity of the different peaks in the occurrence of phytoplankton are very possibly due to such pulses in the life-history of one or more organisms in the plankton.

Cushing (1956, p. 7) after an evaluation of the density of phytoplankton in the catches made by Savage and Hardy (1935) and Savage and Wimpenny (1936), particularly in relation to *Rhizosolenia styliformis*, for the years 1921–34, found that the conditions that produced very high densities in the concentration of the plankton occurred thrice in twelve years. When this is compared with the observations of Wimpenny on *Rhizosolenia styliformis*

(1936 *b*, 1946) and *Biddulphia sinensis* (1956) where he has found a three- to four-year cycle in auxospore-formation, it is quite evident that these intense pulses mentioned by Cushing (*l.c.*) are a result of auxospore-formation and subsequent intense vegetative multiplication of the species as suggested here for *Fragilaria oceanica* by the writer.

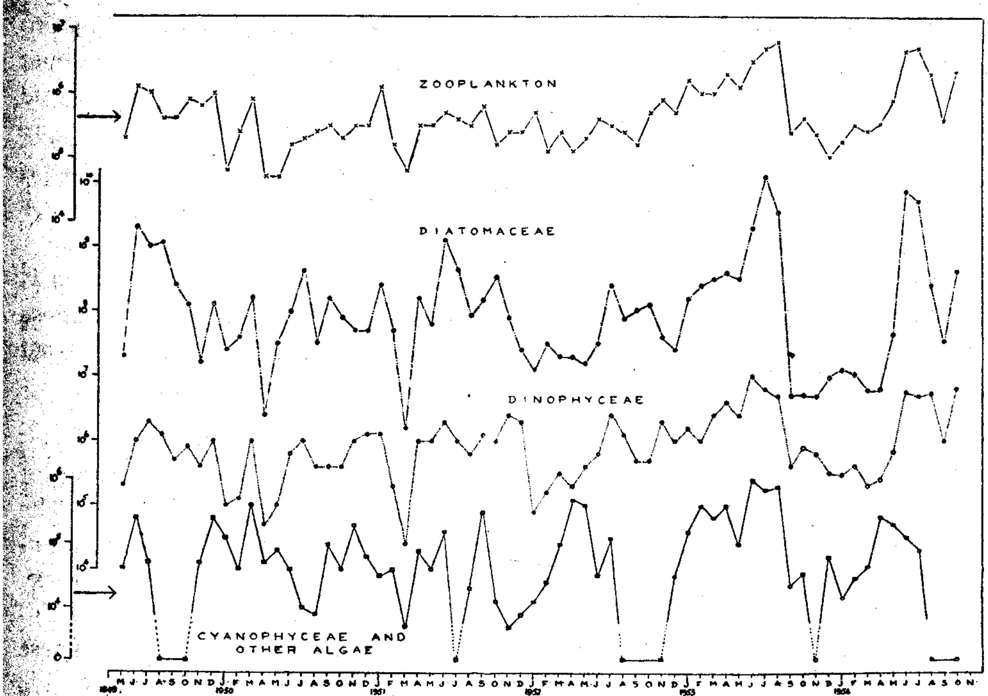
2. *Diatomaceæ*

As the Diatoms constitute the main bulk of the phytoplankton, over 90% by number generally, their seasonal fluctuation resembles that for the total phytoplankton (Fig. 7; compare Table II). They attain the main peak in their occurrence during the south-west monsoon season (June or July) and a secondary peak of occurrence is reached during the north-east monsoon season. In some years there may be one or more subsidiary peaks during both the seasons. The south-west monsoon season appears to be the most favourable one for their growth. During the years of study, the poorest month for Diatoms was March 1951 and the richest, July 1953. In general, the Diatom content of the water was richest in 1953–54, followed by 1949–50, 1951–52, 1952–53 and 1950–51. There appears to be a cyclical change in the intensity of the blooms as was already indicated when dealing with the total phytoplankton, alternate years being somewhat richer than the intervening ones. Further, very intense blooms occur farther apart, after a lapse of a few years of lesser intensity, *e.g.*, 1949–50 and 1953–54. This may (as was seen for *Fragilaria oceanica*) be attributed to the life-history factor of one or more species occurring in bloom in the years concerned. Briefly, the most important genera whose species contribute at times to the bulk production of the phytoplankton are: *Fragilaria, Chætoceros, Rhizosolenia, Coscinodiscus, Asterionella, Nitzschia, Bacteriastrum, Thallassiothrix, Thallassiosira, Actinoptychus.*

3. *Dinophyceæ*

Though the total number of species of Dinophyceæ, recorded as plankton, armoured and naked forms, are nearly as many as those of the Diatomaceæ (Subrahmanyan, 1958) yet, generally, quantitatively they contribute to the bulk of plankton far less than the Diatomaceæ (*cf.* Tables VII, IX and III) except on very rare occasions.

The fluctuation in the quantity of the Dinophyceæ (Text-Fig. 7) is more irregular. This appears to be due to the varied and differing composition of the group, pigmented and unpigmented, armoured and naked, forms occurring at different times, probably governed by different factors. For



TEXT-FIG. 7. Seasonal fluctuation in the quantity (numbers) of Diatomaceæ, Dinophyceæ, Cyanophyceæ, etc., and zooplankton on log. scale (Explanation in text).

example, *Ceratium* spp. are known to react sharply to salinity changes (Graham, 1941 *b*, Graham and Bronikovsky, 1944; Nordli, 1953) and similarly such factors may be active here also. The relationship of some species to environmental factors will be discussed in a later account.

During the south-west monsoon period, the Dinophyceæ occur in large numbers and attain a peak either in June (1951, 1953, 1954) or July (1949, 1950, 1952). At this time, the predominant elements are composed of unarmoured species, pigmented (several species of *Gymnodinium, Prorocentrum,* etc.) and unpigmented (species of *Gymnodinium, Gyrodinium, Noctiluca,* etc.). Among the armoured forms occurring during this season *Dinophysis* spp. and *Ceratium* spp. may be mentioned. *Noctiluca* sometimes constitutes the bulk of the plankton during the season (refer also section of this paper under discoloured water). The armoured forms attain their best development towards the end of the south-west monsoon season or during the following season and one or more peaks of varying intensity occur, at times even surpassing those of the former season (November 1951, October, 1954; Text-Fig. 7). Several species of *Ceratium, Peridinium, Ornithocercus, Dinophysis,* etc., are noticed during these months. On one occasion, in November 1951, *Ornithocercus magnificus* Stein contributed all the bulk and number of the plankton; but such instances are of infrequent occurrence.

4. *Other Algæ*

Among the other plankton elements met with in the water are species of Silicoflagellatæ, Coccolithineæ, Cyanophyceæ and Chrysophyceæ, very rarely Chlorophyceæ and Eugleninеæ. As these occur in very small numbers and infrequently, they have all been combined here and their fluctuation is shown in Text-Fig. 7 and Table III. During certain periods, none of these groups may be present, *e.g.*, August and October 1949, July 1951, August to November 1952, November 1953 and August to October 1954.

During the south-west monsoon season, the Silicoflagellatæ and Chrysophyceæ occur; on some occasions a few of the Coccolithineæ and some of the Cyanophyceæ (*Katagnymene* sp., *Anabæna* sp.) were also present. The same groups are noticed often during the early part of the north-east monsoon months also. From December onwards, species of Cyanophyceæ, chiefly, *Trichodesmium erythræum*, *T. thiebautii*, etc., begin to occur attaining the peak during the warmer months, in February, March or April. These Cyanophyceæ are the only algæ other than Diatoms occurring in noticeable bulk, floating on the surface of the water.

5. *Zooplankton*

Along with the enumeration of the phytoplankton, the faunal elements were also reckoned in the vertical hauls of plankton, primarily to see if there are any relationships present between the two groups. The macro-zooplankton, such as the Medusæ, Salps, etc., are not included, for they are seldom caught in the vertical hauls in appreciable numbers, though at times small Medusæ, Chætognaths and Pteropods occur in such hauls in plenty. The data relate to the total number of all micro-elements, Copepods, larvæ and so on (Text-Fig. 7). George (1953 *a*) has dealt with in some detail the zooplankton of the same region, group-war.

It may be seen that the main peak in the numbers of the zooplankton occur during the south-west monsoon season, in August, immediately after that of the phytoplankton (as seen clearly from the overall average of five years' data). There are one or two more pulses of development taking place in the north-east monsoon season also. In the latter season, though their number is considerably less, their total *bulk* is very high and the size of the individual organisms constituting the bulk also is far larger. Thus, it is seen there is a seasonal fluctuation in the occurrence of zooplankton also, in the case of the phytoplankton, different groups of organisms occurring succession.

The total number of the zooplankton is considerably less than the Diato-ceæ but approaches the Dinophyceæ as regards abundance in terms of mber. During the south-west monsoon period, usually the smaller ele-nts predominate in large numbers, small Copepods, Cladocerans, tinnids, and larvæ of several groups; and, during the following season, ger Copepoda, Pteropoda, Polychæte larvæ, Salps, Chætognatha, Medusæ d so on contribute to the bulk, fewer numbers of larger individuals.

XII. The Phenomenon of Discoloured Water

In this phenomenon, only one species is generally involved. The species volved may also vary from year to year or even seasonally. Thus *Nocti-ca miliaris* on certain occasions, during June to September, causes a pink scoloration of the sea-water by its high concentration (*see* also Bhimachar d George, 1950); a green discoloration is caused by "*green-Noctiluca*" *octiluca* with a green euglenoid symbiont *Protoeuglena noctilucæ* Subrah-anyan, 1954 *a*) when occurring in enormous numbers as it happened in ecember 1952 and March 1953; *Hornellia marina* Subrahmanyan (1954 *b*) used a green discoloration in August and November 1949, September 1952 d September and October 1953; and, a yellow discoloration was caused a new (unnamed) palmelloid Chrysophyceæ in March 1955. Such currences are not a normal feature. Similar phenomena have been corded from various parts of the world (refer Hays and Austin, 1951 for bliography; Feinstein *et al.*, 1955; Howell, 1953; Ingle *et* de Sylva, 1955; argalef, 1956) and on a few occasions elsewhere in India also (Carter, 1858; ornell, 1917; Subrahmanyan on *Gymnodimium*, unpublished).

It is known that some instances of such outbursts of organisms bring out certain changes in the hydrological conditions (Chew, 1953; Subrah-anyan, 1954 *a*, Prasad and Jayaraman, 1954; Slobodkin, 1953; Ketchum d Keen, 1948; Long, 1953) and sometimes also mortality among organisms the water including fish due to effect of toxins, presumably liberated into e water (Galtsoff, 1948 *a*, 1948 *b*, 1949; Gunther, 1947; Gunther *et al.*, 47, 1948; Otterström and Steemann Nielsen, 1939; Stephens, 1948; elubsky, 1951; Shilo and Aschner, 1953; Shilo, Aschner and Shilo, 1953; mmer and Clark, 1946; Sproston, 1946; Subrahmanyan, 1954 *b*, Takano, 56).

Generally, during the outbursts of these organisms in high concentra-n, the normal constituents of the plankton are found to be absent or scarce. It is very likely that this may be due to some deleterious effect produced by their excretions (some visible evidence is available in the case of *Hornellia* (Subrahmanyan, 1954 *b*, pp. 197–98) which resemble " antibiotics " in their action (Lucas, 1949, p. 344; Kylin, 1949). The same explanation may hold good in some instances for the phenomenon of " animal exclusion " postulated by Hardy (1935 *b*, 1936 *a*). More evidence for the antagonistic influence of one organism on another has been recently adduced by Rice (1954; *see* also Pratt, 1943) by culture experiments on *Chlorella* and *Nitzschia*; he concludes that such influences will determine the seasonal fluctuation in the total phytoplankton numbers and of each species, as well as causation of a definite succession of species. Lefevre *et al.* (1949, 1952) have also obtained similar results as those of Rice (*cf.* also Davis, 1954 *b*).

XIII. SEASONAL FLUCTUATION OF THE PHYTOPLANKTON AND ZOOPLANKTON COMPARED WITH EARLIER OBSERVATIONS

1. *Phytoplankton*

It is well established that in all the temperate and colder regions of the world, there is a rhythm both in the qualitative and quantitative distribution of the plankton which is repeated every year though with slight variation in some years. Generally, there occurs a main bloom in the spring and another of lesser intensity in the autumn. This has been found to be so both in the northern and southern hemispheres.† There are reports of several expeditions and cruises which give particulars relating to plankton conditions in these waters, lending support to the general picture obtained by the other individual investigations. According to Allen (1934) the seasonal fluctuation is not so marked at stations in southern California waters as they are in those farther north. Perhaps, in the lower latitudes, the seasons lose their entities and hence such sharp fluctuations characteristic of higher latitudes are not evident nearer the Equator. Unfortunately, as mentioned already in the beginning, we have only very little information for areas in the warmer regions of the world and even these cover only short periods permitting no definite conclusions; a few of them, however, throw some light on the relative standing crops of the regions in the temperate and tropical zones (Allen and Cupp, 1935; Allen, 1924, 1939; Gilson, 1937; Graham, 1941 *a*, Riley, 1938, 1939; Riley, Stommel and Bumpus, 1949).

The accounts for the warmer parts of the world, where there have been some continuity of observations, may be briefly cited here.

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† Owing to paucity of space, a list of references on this aspect is omitted here.

One of the earliest attempts to study this aspect in a warmer region of the world appears to be by Hornell and Nayudu (1923) who studied the plankton on the west coast of India at Calicut in connexion with their work on the life-history of the Indian oil-sardine, *Sardinella longiceps* Cuv. *et* Val. They speak of an outburst of Diatom bloom in May, which fell somewhat in June and reached the maximum in July, and fell off again to a minimum in December. There were small pulses of abundance in January and February, a fall in March and a rise in April.

According to Menon (1945), on the Trivandrum coast, farther south of Calicut, the Diatoms gradually increase from January to a maximum in May and there is no clear secondary maximum. More work continuously for a number of years is needed here for a clear elucidation of the cycle.

In the Bombay harbour, one year's investigation indicated that phytoplankton was scarce from May till August after which there was an increase till the maximum was reached in January or February (Gonzalves, 1947). The cycle noted here is, very probably, influenced by the peculiar environment of a harbour; it is possible, that the cycle of phytoplankton bloom in the sea off Bombay beyond the harbour pollution might be more in line with that described by the writer in this account.

At Calicut, according to Chidambaram and Menon (1945), who had no data for the crucial south-west monsoon months of June, July and August, the volume of plankton was at its maximum in September; there was a fall in October and November, a slight rise in December, and scarcity in January following. From February to May, Plankton production was more or less steady with minor fluctuations occasionally.

George (1953 *a*) made a general study of the plankton at Calicut for about three years. He found the occurrence of the peak period for phytoplankton in the south-west monsoon months. A second peak may occur in December or January. In general our observations are in agreement.

Coming to the east coast of India, Menon (1931), who investigated the plankton for two years at Madras, found that the Diatom maximum occurs in April–May. There is a slight fall in June, a rise in July and a rapid fall thereafter. A secondary maximum occurs in December. Further, according to him (*l.c.*, pp. 493–94) the general maximum is a culmination of a regular and constant Diatom increase beginning in September unlike the European waters where it is a sudden rise beginning in March. The Peridiniales also attain their maximum in May.

Ramamurthy (1953 *b*) who made study of the plankton at Madras over 20 years after Menon, for about 14 months, noticed a difference in that while August–September were months of scarcity for Diatoms in Menon's records, they were not so in his records. According to him, February, April, May, August, September, November and December were rich months while January, March, June, July and October were poor months.

At Waltair (farther north of Madras) Ganapati and Rao (1953) and Ganapati and Murthy (1955), in studies lasting for a year in each instance, report a spring maximum extending from February to April and an autumn maximum from October to December (Ganapati and Rao) and November (Ganapati and Murthy).

On the south-east coast of the Indian Peninsula, at Krusadai in the Gulf of Mannar, Chacko (1950) states that the Diatom maximum is usually from June to November. In the same Gulf, in a study covering two years, 1950 and 1951, according to Prasad (1954 *a*) the phytoplankton cycle shows more than one maximum during the year; a peak in February–March due to local flowering of a single species and a summer, August–November, peak constituted by several species of Diatoms. In his further study, extending from July 1951 to June 1953, the same author (Prasad, 1956) found at a Gulf of Mannar Station, three distinct blooms of phytoplankton, in January, April–May and October–November. In the Palk Bay station, the magnitude of the crop was of a higher order and two peaks of production occurred, one single prominent one during the summer months April–June, and another in October–November.

There are some accounts available from other warmer areas of the world which may be of interest here. In the Great Barrier Reef region, Marshall (1933) could not establish a real seasonal fluctuation for the phytoplankton; moreover, the period of investigation extended only for a year there.

Haneda (1942) found in Palau Island in the tropical Pacific periods of maximum and minimum in the plankton content of water.

Kow (1953) found in the Singapore Straits, almost on the Equator, the main bloom of phytoplankton occurring in April or May; and there were peaks, one or more, of varying intensity at other times of the year.

The results of the present investigation at Calicut on the west coast of India, covering a period of over 5 years, clearly shows that there is a seasonal variation in the abundance and occurrence of the phytoplankton organisms which recurs year after year, though with slight variation in the intensity of the bloom and its time of occurrence, even as has been observed in the temperate and colder seas. The maxima occur during the south-west monsoon period, in June or July. In some years there is a sharp fall in the quantity of phytoplankton in August, very probably due to the grazing effect of the zooplankton which attain their primary maxima about that time. The phytoplankton is poorest generally in the month of November and one or more pulses of production occur during the north-east monsoon months, between December and April. Thus, in the Indian waters also, it may be stated with certainty that there is a double or bimodal oscillation in the fluctuation of the standing crop of phytoplankton; however, the period of occurrence of the bloom varies from place to place somewhat and there is no general uniformity as seen in the temperate regions. The factors responsible for the production of phytoplankton and for the variation in the timing of the bloom will be discussed elsewhere (Part II).

2. *Zooplankton*

As in the case of phytoplankton, the fluctuation in the abundance of zooplankton has been thoroughly investigated in the temperate and colder seas both in the northern and southern hemispheres. It has been found that there is a pronounced maximum in late spring or summer and a minimum in the winter and occasional pulses of abundance sometimes at other periods in between (*e.g.*, Harvey *et al.*, 1935; Russel, 1936 *c*; Johnstone, Scott and Chadwick, 1924; Wiborg, 1944, 1954; Deevy, 1952 *a*, *b*; Dakin Colefax, 1940; Sheard, 1949). Data for the tropical and sub-tropical regions of the world are indeed few as there have been no continuous investigations in these regions. The accounts that are available confirm the presence of a seasonal fluctuation reported in the present account.

Menon (1931) found the period of abundance of the zooplankton in the Madras waters between November and February. On the Trivandrum coast (Menon, 1945) the data for zooplankton show no clear peaks of abundance, though December to February in 1938–39 and February to May in 1939–40 may be considered as having a high zooplankton content; in the former year, the zooplankton content was of a higher order. In the Gulf of Mannar near Mandapam, in a study covering 1950 and 1951, Prasad (1954 *a*) found a bimodal cycle for the zooplankton, with one peak in February–April and the maximum peak in October, with a minimum in July. In a later account the same author (Prasad, 1956) found a bimodal cycle both in the Gulf of Mannar and the Palk Bay, the two stations, however, differing in the pattern of the cycle; while one station showed abundance, in the other the zooplankton was poor and *vice versa*.

In the Great Barrier Reef, Russel and Coleman (1934) could find no sharp fluctuation in the abundance of the zooplankton as in the temperate regions; but, the quantity did show a fluctuation at different seasons and as the period of study was only one year, it could not be stated whether the cycle would repeat itself. King and Demond (1953) and King and Hida (1954) were able to find a seasonal abundance in the zooplankton content of the water in the Central Pacific and Hawaiian waters respectively. Kow's (1953) data for the Singapore Straits suggest a possible seasonal fluctuation as shown by the abundance of the Copepods which form over 70% of the zooplankton population.

In the present area, the main peak in the numbers of zooplankton occurs during the south-west monsoon season, in August, immediately after that of the phytoplankton (as reckoned from the average of 5 years' data). There are one or more pulses of development during the following north-east monsoon season. As already mentioned, the zooplankton exceeds the phytoplankton in bulk on most of the occasions in the latter season though numerically fewer. As in the case of the phytoplankton, although the results of all the investigations agree in the record of a seasonal abundance in all the places investigated, differences occur relating to the time of their peak development and the intensity of the crop.

XIV. PHYTOPLANKTON-ZOOPLANKTON RELATIONSHIP

It is well known that zooplankters depend on phytoplankton for food, and naturally, some relationship is to be expected between them and their respective distribution. This relationship has been dealt with and reviewed by many workers in the past, mostly based on work in the temperate and polar waters (Harvey, 1934 *b*; Harvey *et al.*, 1935; Bigelow, Lillick and Sears, 1940; Mare, 1940; Hart, 1942; Gauld, 1950; Marshall, Nicolls and Orr, 1934; Marshall and Orr, 1952; Marshall, 1949; Barnes and Barnes, 1956; Wimpenny, 1936 *a*; Hardy, 1935 *b*; Lucas, 1936 *a*; 1947, 1949 and 1955; Steemann Nielsen, 1937 *a*; King and Demond, 1953; King and Hida, 1954; Clarke, 1939; Riley, 1946; Fleming, 1939 and Bainbridge, 1953). The substance of these investigations indicates that an abundance of phytoplankton leads to an increased development of zooplankton and the relationship between them is *direct* and the *inverse* relationship at times recorded is caused by the grazing down of the phytoplankton population by the zooplankton. Further, it was also held that the inverse relationship was brought about by the animals avoiding areas rich in phytoplankton (Hardy, 1935 *b*; Lucas, 1936 *a*) presumably owing to the effect of external metabolites of the plant population which adversely condition the medium (Lucas, 1947, 1949 and 1955).

In the following brief account some of the relevant facts emerging from the foregoing investigations are discussed with reference to observations made here, besides referring to one or two recent papers.

An extensive experimental study of the relationship between phyto- and zooplankton by Bainbridge (1953) has shown that the inverse distribution met with may be accounted for by a combination of migration and grazing and the exclusion mechanism as a means of producing the inverse relationship is operative only in instances of monospecific blooms of toxic flagellates, such as *Gonyaulax.*

Kow (1953) found a direct relation between phytoplankton and Copepods in that their peak of occurrence coincided.

In the Indian waters, Prasad (1956) found at a station in the Gulf of Mannar that the relation between phytoplankton and zooplankton was inverse, whereas at a station in the Palk Bay, the relationship was direct. The Copepod-Diatom relationship was of a similar nature at the respective stations (*see* also Prasad, 1954 *b*).

The present investigation indicates that in the study of phyto-zooplankton relationhsips, the time factor or seasonal factor, has also to be taken into consideration. It was pointed out earlier that in terms of the *bulk* of the standing crop, the biological year shows two clear periods, (i) the predominantly phytoplankton period, the south-west monsoon season, May to September–October, and (ii) the predominantly zooplankton period, the north-east monsoon months, October–November to April following.

The data collected during the period of five years show that the number of zooplankton elements tends to increase gradually with the increase of the phytoplankton elements (number and pigment units) from the beginning of the south-west monsoon season. This may be seen from a casual examination of Table XIII, in which the five years' data are averaged (*cf.* also Tables II and III; and also Text-Fig. 7). The zooplankton (in terms of *number*) attains its peak of development at the same time as or immediately following the peak in the phytoplankton production. The trend of increase of both indicating a " direct " relationship is unmistakable though study of individual samples may not show a " proportionate " increase between them, this being due to the changes in the composition of the flora and fauna alike. On certain occasions, when the phytoplankton is composed of mainly setoid

TABLE XIII

Phytoplankton-Zooplankton relationship

Month	Zooplankton number	Phytoplankton number × 1,000,000	Phytoplankton Plant pigment units (Harvey)	Remarks
May ..	403,000	80	2,204	
June ..	1,143,000	1,071	3,684	1. The figures given are the average of five years' data
July ..	1,357,000	3,405	8,002	
August ..	1,393,000	971	3,782	
September ..	366,000	134	3,020	2. The Dinophyceæ including *Noctiluca* have been reckoned under phytoplankton
October ..	413,000	134	2,342	
November ..	459,000	25	1,412	
December ..	430,000	48	1,512	
January ..	741,000	100	1,276	
February ..	382,000	71	1,516	
March ..	518,000	104	1,370	
April ..	610,000	115	1,370	

forms like *Chætoceros* spp., *Bacteriastrum* spp., *Rhizosolenia* spp., etc., a fall in the number of zooplankton, somewhat proportionate, becomes evident which might be interpreted according to Hardy as " animal exclusion " owing to a deleterious influence exercised by these forms on the faunal elements leading to a patchy distribution of the plankton. Plenty of examples of patchy distribution are also available from the Antarctic and the seas around the British Isles (Lucas, 1936 *b*, 1940; Lucas and Macnae, 1941; Hardy, 1935 *a*, *b*; 1936 *a*, *b*; 1955; Hart, 1934; Savage, 1930; Savage and Hardy, 1935; Savage and Wimpenny, 1936; Wimpenny, 1936 *a*; Rae and Fraser, 1941). In contrast, when the plant forms involved are non-setoid, *e.g.*, species of *Coscinodiscus*, *Thalassiosira*, *Fragilaria*, and so on, a proportionate increase of animals is noticed. In general, during this season, the relationship between phyto- and zoo-plankton appears to be the same as recorded by Marshall, Nicolls and Orr (1934) and Steemann Nielsen (1937 *a*), *viz.*, a direct one. This is supported by the presence in the plankton samples of developmental stages of many groups of animals in considerable numbers. In terms of total *bulk*, the zooplankton during this season is no match to the phytoplankton *bulk*, the conditions for the production of the latter being at its optimum. Most of the animals are small-sized forms; nevertheless, the trend of their increase shows that they feed and reproduce on account of the increased availability of plant food. Among the zooplankton organisms met with during the season are Foraminifera, Radiolaria, Tintinnids, Polychæte larvæ, larval Bivalves, Cladocerans, small Copepods, Nauplii, Amphipods, Lamellibranch larvæ and towards the end of the period, Salps, Tunicates and Prawn larvæ, also (*see* also George, 1953 *a*).

During the north-east monsoon season, the general picture of the standing crop is very different. Except on a few occasions, when the phytoplankton bloom is at its second peak of production, zooplankton is seen *prima facie* to dominate the *bulk* of the standing crop. The majority of the zooplankton forms are larger in size compared with those of the earlier season; and it may be stated here that the Copepod element is the dominant faunal form in the plankton and of utmost importance in the economy of the sea as it is elsewhere also. Besides the Copepods, the forms occurring include Salps, Medusæ of varying sizes, Ctenophores, Chætognaths, Decapod and Molluscan larvæ and so on (*cf.* also George, 1953 *a*). However, the relationship seen in terms of *number*, direct increase in the number of zooplankton elements with an increase in the *number* of phytoplankton, is also seen during this season except on a few rare occasions as on November 7th, 1949, March 12th and 19th, 1951, and April 2nd, 1951, when even the number of zooplankters were above or equal to that of the phytoplankton, which obviously indicates that the production rate of phytoplankton has declined and/or grazing rate has increased, resulting in an inverse relationship such as that mentioned by Steemann Nielsen (*l.c.*). Such a situation lends support to the view propounded by Fleming (1939) also. Moreover, it is seen that the rate of fall in the production of phytoplankton during the north-east monsoon season as noticed in terms of the magnitude of the standing crop is of a higher order than the rate of fall in the number of zooplankton during the same period; on the other hand, the *quantity* of animal matter has increased considerably, obviously at the expense of the phytoplankton. The conspicuous fall in the quantity of phytoplankton in November generally (Text-Fig. 4) is very probably due to the heavy grazing by the increasing number of larger zooplankton organisms and this accords with the suggestion of Harvey (1934 *b*) and Harvey *et al.* (1935) for the English Channel.

Data relating to the dry weight estimations of the standing crop, the *biomass*, throw some interesting light on the interrelationships of the phyto- and zoo-plankton community. It was pointed out earlier that the sharp fluctuation seen, when the standing crop is reckoned in terms of number and pigment units, is not seen when the same is viewed with data relating to dry weight estimations; and, further, the overall ratio of the crop between the two seasons, a predominantly phytoplankton one and the following predominantly zooplankton one, shows a close approximation indicating a balance in the biological content of the water as between plant and animal life. This seems to indicate that the relationship between these two forms of life, animal and plant, in the sea, is not one that can be ascertained by the present methods of the estimations of the standing crop. The relationship is one that involves a large number of factors, the rate of increase of plant matter, the rate of grazing by animals, the quality of food consumed by the animals, mode of feeding—indiscriminate or selective—and hydrological conditions affecting the biological elements. The qualitative nature of the flora and fauna changes frequently; it is possible that certain animals are associated with a particular type of vegetation and so on. Too much emphasis appears to have been placed on the *number* factor in judging the relationship of the phyto- and zoo-plankton in the past, of course for want of a better method. The *bulk* also needs to be considered as may be seen from the present investigation. Further, in experimental investigations, the species employed, particularly phytoplankton ones, are those that grow easily under laboratory conditions; these forms are not found generally in quantity in nature. Inability to reckon all these may, to some extent, explain the slight variations in the interpretations put forward of observations from nature.

The relationship between phyto- and zoo-plankton as it obtains here, therefore, may be generally considered to be *direct* in terms of *number* of organisms and *bulk* during the south-west monsoon season; and direct in terms of *number* but inverse in terms of *bulk* during most of the north-east monsoon season. It is not possible to say how exactly this relationship is brought about in these waters in the absence of information on several aspects; it is possibly brought about both by the vertical and horizontal migration of the faunal elements as suggested by Bainbridge (1953) and, from the presence of developmental stages, it may be stated that a good number grows and thrives *in situ* also among the same plankton environment, even in dense patches of phytoplankton.

Sometimes, during the south-west monsoon season, when there is heavy production of phytoplankton, surface plankton catches were found to consist of mainly zooplankton—Copepods and Cladocerans predominantly—while bottom samples of plankton were mainly of phytoplankton with some zooplankton. On such occasions, it has been noticed that the salinity of the surface water was very low, even below 20‰ whereas water at the depth of 15 metres showed a salinity of *circa* 30‰. Further, on many such occasions, the phytoplankton also was composed mainly of setoid forms; mention of the possibility of such a reaction of the fauna to such floral elements has already been referred to. It is possible that salinity also may have a relation connected with this reaction; the Diatoms may have sunk owing to the very low specific gravity of the surface water and, as their concentrations may have increased so much in the bottom layers, some zooplankton may have migrated and aggregated at the surface as they could, probably, tolerate a much lower salinity. Obviously, the phytoplankton could not, for the specimens seen at the surface were mostly dead.

Before concluding this section, the " animal exclusion " hypothesis of Hardy, mentioned earlier, may be examined in relation to the occurrences here. According to Bainbridge (1953) this operates in areas where there are monospecific blooms of a toxic flagellate. Some observations on the plankton of the west coast of India lend support to this view of Bainbridge. Sometimes blooms of green *Noctiluca* (*Noctiluca* with the symbiont *Protoeuglena noctilucæ* Subrahmanyan, 1954 *a*) occur in the waters here and also on the south-east coast of India (Prasad, 1953; Prasad and Jayaraman, 1954). On the west coast, whenever the concentration of this form was so high as to discolour the water, it was found that virtually no other organisms were present in the water, whether Diatoms or zooplankton. This has been observed on the east coast also, where, in addition, it was noticed that the

" Choodai " (*Sardinella* spp.) become scarce when this *Noctiluca* occurred there (Prasad, 1953). Again, during the occurrence in high concentration of this *Noctiluca* certain changes in the hydrological conditions have been observed, particularly related to the silicate content of the water (Subrahmanyan, 1954 *a*; Prasad and Jayaraman, 1954). This aspect is discussed by the writer later below (Part II). It may be mentioned here that elsewhere also hydrological changes have been noticed connected with such blooms, *e.g.*, the " Red Tide " on the Florida coast (Chew, 1953; Slobodkin, 1953; Ketchum and Keen, 1948; Long, 1953).

The writer would like to point out here that no deleterious effect appears on the plankton organisms or fishes when the common pink *Noctiluca miliaris* Sur. occurs, even in high concentrations, discolouring the water pink. Often this takes place during the south-west monsoon season on the west coast of India and at such times large quantities of phytoplankton as well as zooplankton also occur along with it. However, it may be mentioned here that Aiyar (1936) has reported mortality of fishes on the Madras coast, and Bhimachar and George (1950) also report a set-back to the fishery on the west coast during the occurrence of this *Noctiluca* (*cf.* however Subrahmanyan, 1954 *b*, pp. 188–97).

Again, on the west coast, *Hornellia marina* Subrahmanyan, a Chloromonadine flagellate, when occurring in sufficiently large quantities as to discolour the water green, appears to have a deleterious effect on all other plankton organisms and often causes fish mortality (Subrahmanyan, 1954 *b*). The extrusion of a certain substance seen in this form at times (Subrahmanyan, *l.c.*, p. 197) presumably brings about a toxic condition in the water for other organisms.

The other instance of a monospecific bloom was when an unnamed Chrysophycean palmelloid alga (Subrahmanyan, unpublished) occurred here discolouring the sea-water somewhat yellow. Most of the usual organisms in the plankton were absent except an odd Diatom here and there.

In a series of articles, Lucas (1936 *a*, 1947, 1949, 1955) has discussed and pointed out the possibility of a non-predatory relationship between the phyto- and zoo-plankton, especially, brought about by *ectocrines* (external metabolites having important environmental significance) which range from toxins to vitamins and hormones in their ecology and which might lead to a biological conditioning of the water by the organism or organisms which precede. It is very possible that this type of relationship becomes pronounced only when a monospecific bloom occurs. These observations made on the west coast of India would appear to lend some support to the statements of Lucas mentioned above and of Rice (1954) explaining mutual antagonisms between certain organisms.

In the literature, one finds mostly some peridinians—*Gymnodinium* spp., *Gonyaulax* spp., etc., associated with the type of phenomena described above (Hays and Austin, 1951; Galstoff, 1948 *a*, *b*, 1949; Davis, 1948; Allen, 1933, 1940, 1942 *a*, 1942 *b*, 1943, 1946; Santos-Pinto, 1949; Hornell, 1917). So far, the organisms described here have not been reported and, therefore, are of special interest.

The researches in the North Sea on the Diatom and zooplankton patches and the relationship of the same to the herring are of interest in this connexion (Pearcy, 1885; Bullen, 1908; Hardy, 1924; 1926, 1936 *a*, *b*; Savage and Hardy, 1935; Savage, 1930, 1932; Savage and Wimpenny, 1936; Lucas, 1936 *b*, 1940, 1942; Lucas and Macnae, 1941; Lucas, Marshall and Rees, 1942; Henderson, Lucas and Fraser, 1936; Henderson, 1936). However, in a recent contribution, Cushing (1956), after special observations on this aspect of exclusion, comes to the conclusion that these instances of " exclusion " in the North Sea are not of general occurrence at the concentrations of the Diatoms in the patches met with and the earlier conclusions of the authors were due to some discrepancies in the timing of the investigations. Much higher concentration would be required to produce such an " exclusion ". Bainbridge's (1953) conclusion on such occurrences, as also that of the writer already cited, would appear to support Cushing's view.

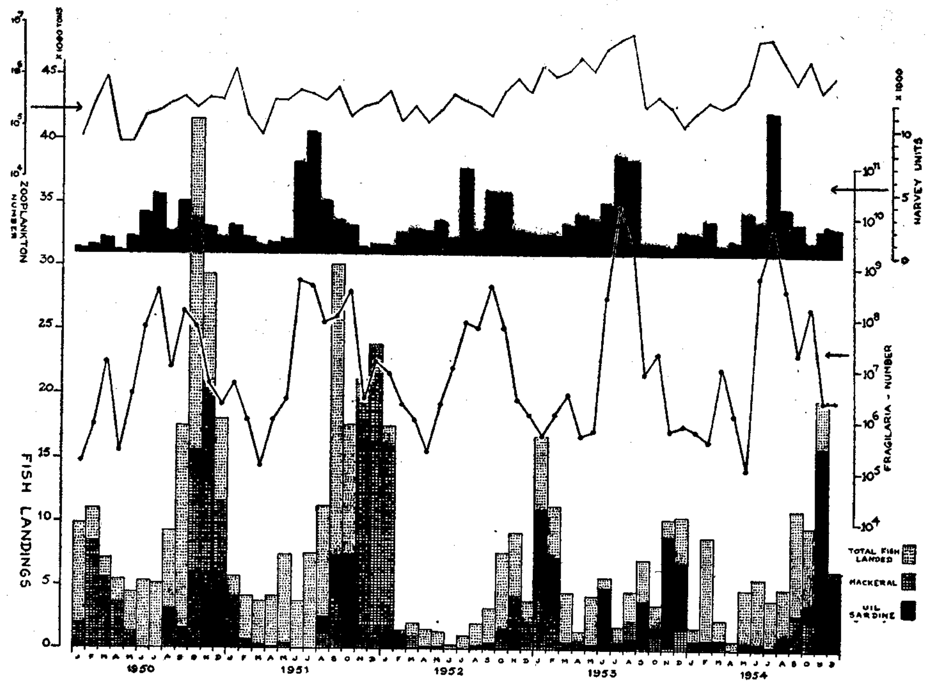
XV. Relationship between Plankton Production and Fisheries

The object of fishery research is mainly to devise a method for the forecasting and controlling of future fish supplies. As the phytoplankton elements, the main synthesizers of food in the sea, fluctuate in relation to so many environmental factors, they form an important and convenient basis in assessing the fluctuations of the stock of edible fish. It is well known that a rich phytoplankton crop leads to a rich zooplankton crop and good survival of young fish (Russel, 1936 *b*; Harvey, 1950). Delsman (1939) states: " Where no rich plankton develops, no rich macrofauna, no abundant fish population can either be expected." Hesse *et al.* (1951) state that " the dependence of various elements of the food chain on a preceding one conditions the distribution of the larger forms". By means of experiments carried out by application of inorganic fertilizers to ponds, Smith and Swingle (1939) have clearly demonstrated that increased plankton production increases fish production and a direct relationship between average production of plankton and production of fish exists, though no direct relationship was evident between zooplankton alone and fish production (*cf.* also Tal and Shelubsky, 1952). The experiments carried out for marine fish cultivation also by artificial fertilization of sea lochs in Scotland bring out the rôle of plankton in the production of fish; the growth of fish was greater owing to increased supply of food consequent on increased production of plankton (Gross *et al.*, 1944, 1946; Gross, 1947, *a*, *b*, 1949; 1949 (50), *a*, *b*; Raymont, 1947, *a*, *b*, 1949, 1950; Marshall, 1947; Marshall and Orr, 1948; Orr, 1947; Gauld, 1950). As Lewis (1929, p. 156) has observed " by learning the relation of the fish to its food environment, it may become possible by examinations of fluctuations in the quantity of fish food, to evaluate the significance of one of those factors that determine in advance the relative abundance of fish for certain year classes. It may also become possible to determine the cause for the apparent migration of certain fish".

The Indian oil-sardine, *Sardinella longiceps* Cuv. *et* Val., and the Indian mackerel, *Rastrilliger kanagurta* Cuv., constitute the bulk of the fishery resources of the west coast of India and quite a considerable number of the people of the region is dependent on these fisheries for their livelihood. Nair and Chidambaram (1951) have discussed the magnitude and importance of the oil-sardine fishery in the economic life of the people of the west coast and later Nair (1952) has discussed the revival of this fishery after a long period of lean years. Pradhan (1956) has reviewed the mackerel fishery of Karwar, the most important centre for this fish on the west coast. The other fishery resources are contributed by prawns, white sardines, the flat fish, *Cynoglossus*, etc. (*cf.* also Panikkar, 1952; Rao and Panikkar, 1949).

In Text-Fig. 8, the total landings of fish for an extent of the west coast of India, about 150 miles of the coast-line, north of Ponnani to Mangalore (Zone 9 of the Central Fisheries classification), is graphically shown as also the landings of the oil-sardine and the mackerel. In the same figure, phytoplankton data are represented as Harvey Units, and total zooplankton data and that for *Fragilaria oceanica* Cleve in numbers. The general trend of the fluctuation of fish landings shows that the quantity landed goes up following the bloom of phytoplankton or even, sometimes, during the height of the bloom as in June 1953. The fish landings at Calicut also reflect the same trend as Zone 9 mentioned above and hence is not treated separately.* A clearer appreciation of the relationship between plankton production and fisheries is possible only if the fishes concerned are considered in relation to their food habits and the constituents in the plankton. Therefore, the present

* My thanks are due to Mr. P. K. Jacob for supplying me with data relating to landings of the oil-sardine and mackerel at Calicut collected by the Madras State Fisheries Department.



TEXT-FIG. 8. Seasonal fluctuation in the quantity of phytoplankton, zooplankton and *Fragilaria oceanica* in relation to the total commercial fish landings and of the mackerel and oil-sardine on the west coast (Explanation in text).

knowledge we have on the oil-sardine and mackerel are considered here with reference to plankton data and compared with similar observations elsewhere to explain how such relationships are brought about.

The oil-sardine fishery.—In the course of his investigation on the oil-sardine, Nair (1952) established that the oil-sardine is a plankton feeder, feeds mainly on phytoplankton and shows a preference to the Diatom, *Fragilaria oceanica* Cleve. According to Subrahmanyan (unpublished), this Diatom has a life-span of three to four years, during which the quantity of this Diatom in the plankton fluctuates, there being outstanding peaks of production at intervals at about 4 years or so brought about by its mode of reproduction. Similar cycles of abundance have been recorded for *Rhizosolenia styliformis* and *Biddulphia sinensis* in the North Sea (Wimpenny, 1936 *b*, 1946, 1956; Cushing, 1956). A study of the fluctuation in the quantity of this Diatom, *Fragilaria*, and the oil-sardine landings led to a short account by Nair and Subrahmanyan (1955) in which it was pointed out that the bloom of this Diatom could be used as an indicator of the abundance of the oil-sardine.

In Text-Fig. 8, the quantitative fluctuation of *Fragilaria* during the years 1950–54 and also the oil-sardine landings are depicted. The oil-sardine fishery commences with the commencement of the *Fragilaria*-bloom in the waters here. It would appear that as more and more sardines invade the waters (as evidenced by increasing landings of fish) this plankton is grazed down and becomes apparently almost depleted. The grazing activity would seem presumably to start at the periphery of the phytoplankton patch during the early part of the season and then gradually extend inward until finally the bloom is grazed down. (It may be mentioned here, that during the early part of the season, fishing activity is very much limited because of the inclement weather conditions and, consequently, full exploitation of the fishery during this season does not take place. This point is referred to later below.) Savage and Wimpenny (1936) have observed a massing of both zooplankton and the herring on the edges of the Diatom patches in the southern North Sea and great intensity of fishing takes place along the edge of the phytoplankton patch.

After the main peak of the fishery has been attained and passed following the main bloom of *Fragilaria*, it has been found, on some occasions, that if an increase of this Diatom occurred in the waters, sardine also became available and once again the Diatom is grazed down along with some other elements. Even when *Fragilaria* is apparently absent in the usual plankton catches, gut contents of sardines have shown *Fragilaria* in not inconsiderable numbers; the scarcity of this Diatom in the water may, perhaps, be due to the grazing effect on it by the fish. Therefore, it seems probable, that the relationship seen between this phytoplankton element and the oil-sardine is somewhat similar to that seen in the instance of phyto- and zoo-plankton relationship, *viz.*, a direct one to start with which becomes inverse owing to the grazing rate exceeding the multiplication rate of the Diatom.

Obviously, this relationship leads to the query whether one could expect increased oil-sardine catches based on the intensity of the monsoon bloom of *Fragilaria*; in other words, could the intensity of the bloom of *Fragilaria* be an indication of the prospects of the oil-sardine fishery of the following seasons? Nair and Subrahmanyan (1955) adduced some evidence which indicated that an increase in the abundance of this diatom could mean increased oil-sardine catches. Records show (Subrahmanyan) that between the years 1949 and 1954, *Fragilaria* had two outstanding peaks of production, in 1949 and 1953 and it was surmised that the bloom of 1949 helped to revive the fishery leading to increased landings in 1951–52 compared with earlier years, which culminated in the outstanding landings of sardines for severa decades in 1953, in which year *Fragilaria* also showed an outstanding peak of production (Text-Fig. 8).*

The relationship mentioned above between the oil-sardine and *Fragilaria* naturally raises the question of the feeding habits of this fish. The observations (Nair, 1952) show that it is not *exclusively* dependent on *Fragilaria* but only appears to show a *preference* for it. Many other species of Diatoms as well as other organisms have been reported from its gut content. In the absence of a detailed quantitative study of the gut contents in comparison with the plankton content of the water, it is not possible to come to any conclusion on this subject. However, the observations on the California sardine are of interest here. Lewis (1929) found that Diatoms and Dinoflagellates are used chiefly as food by this sardine though, occasionally, Copepods also are eaten; a definite relation exists between numbers and species present in the digestive tracts of the sardines and in the surface plankton about them. His observations would indicate that there is some selective intake of food. This view of Lewis's is disputed by Parr (1930) who states that ingestion of phytoplankton is incidental and zooplankton forms are the real objects of special pursuit. Radovich (1952) after the analysis of the food of the same sardine, *Sardinops cærulea*, came to the conclusion that this form is a particulate as well as a filter feeder (also *Cal. Co-op. Sardine Res. Program*, 1952, p. 24). The presence in the gut of the oil-sardine here of several other species from the plankton and the absence of *Fragilaria* on some occasions (when this Diatom is not present in the water obviously) would indicate that the large quantities of *Fragilaria* when present is due to a *particulate* form of intake of food.

The mackerel fishery.—Studies made so far on the feeding habits of the mackerel show that the mackerel is an omnivore (John and Menon, 1942; Chidambaram, 1944; Bhimachar and George, 1952). Zooplankton, particularly, Copepods, constitute the bulk of its food. It may be mentioned that Copepods generally are the dominant elements of the zooplankton.

Discussing the correlation between mackerel food and the plankton, Bhimachar and George (1952) state that the composition of the plankton in the water is reflected in the gut content of the mackerel except for certain " non-edible " forms like *Noctiluca*, Salps, Medusæ and so on, and food composition varies from season to season. A somewhat similar relationship

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* The next outstanding bloom for *Fragilaria* was expected in 1957 south-west monsoon (writer's calculation); this has come true as also a very good oil-sardine fishery during the 1957–58 fishing season.

has been found by Kow (1950) in his observations on the food habits of the fishes of Singapore Straits. These accounts would indicate that the mackerel concerned is not quite discriminate in its mode of intake of food except to the extent of " avoiding " certain forms (*cf.* Pradhan, 1956, pp. 168–71, also).

The fluctuation of the mackerel fishery also is shown in Text-Fig. 8. Though no such close relationship between the mackerel and any other factor is evident as was found between *Fragilaria* and oil-sardine, it may be seen that there is, to some extent, a direct relationship to start with between phyto- and zoo-plankton on the one hand, and mackerel on the other which, later on, as the consumption of plankton increases, becomes inverse. It may be seen from the figure that mackerel catches are of a higher order when the standing crop of zooplankton is lower; in other words, zooplankton crop never reaches a high peak when mackerel is present. Until more is known about the feeding habits of the mackerel and of the quantitative composition of the food ingested, and the cycle of occurrence of the several organisms constituting its food and their relative abundance in the water, no indicator organisms can be specifically recognized.

As there is not much information available about the food of several other fishes of commercial importance on the west coast of India no further attempt at correlation is possible now (*cf.* however Seshappa and Bhimachar, 1955). However, it may be mentioned that considerable quantities of prawn are landed here which also form an important fishery during the months following the main outburst of phytoplankton. The food of the prawn also consists of considerable quantities of phytoplankton elements, particularly *Fragilaria*, *Coscinodiscus*, *Pleurosigma*, *Navicula*, *Cyclotella*, etc. (Menon, 1951), on some of which the prawn feeds when the elements sink to the bottom while others feed at the bottom. The food of *Kowala coval* (Cuv.), the white sardine, also consists of plenty of phytoplankton elements (*see* Nair, 1951, Table I). It may be noted that the peak of the fishing season succeeds the main production of phytoplankton on this coast.

It may be pointed out that with the commencement of the south-west monsoon, owing to the stormy weather, regular fishing operations are at a standstill, till calmer conditions prevail in the sea, about August. So, absence of fish landings during this early part of the period may not be entirely due to the fishes being absent from the waters, but absence of fishing operations. It may be seen from the data that good landings can be expected even during the peak period of the monsoon as may be seen from the landings made in June 1953, when the fish mainly caught was the oil-sardine, a phytoplankton feeder (Text-Fig. 8). Fishing operations are possible during this season in some years, when mud bank formation occurs along this coast, as it did in 1953. During the occurrence of mud banks, as mentioned earlier, the sea is calm in its environs and fishermen are able to take their canoes out; otherwise, the strong surf near the shore during rough weather prevents them from launching their boats. The topography and presence or absence of the mud banks seem to influence the fishing operations here during these early south-west monsoon months. It is possible that during these months also good catches of fishes can be obtained if it were possible to carry out fishing operations.

Similar observations on the pelagic fisheries and plankton production made elsewhere also lend support to those recorded here. In the case of the Atlantic mackerel, *Scomber scombrus,* according to Sette (1950, pp. 294, 305) " mackerel catches coincided with plankton concentrations to suggest that the mackerel tended to travel or tarry in waters richest in plankton content. However, if the feeding of the mackerel reduces a zooplankton concentration rapidly severely, one would expect an intially positive correlation between mackerel and zooplankton to become a negative one as feeding proceeds ". After giving more details about the feeding of the mackerel, Sette (*l.c.*, p. 295) observes that " while there is no evidence that local mackerel and zooplankton concentrations tended to coincide with each other, the agreement of plankton abundance and the presence of the mackerel in general suggests that evolutionary processes have brought about a habit pattern in which this species reaches various areas along its route of spring migration at a time when, on the average, feeding conditions are favourable". It is possible that what has just been stated here about the Atlantic mackerel may prove equally true of the oil-sardine and the mackerel of this coast of India.

The other example concerns the *Calanus*-herring relationship in the northern waters which has been studied in great detail from all aspects—production of *Calanus*, abundance of same, feeding of herring on *Calanus* and so on—by several workers (Bigelow, 1922, 1926; Bogorov, 1934; Boldovsky, 1941; Bowers and Williamson, 1950; Cheng, 1941; Cushing, 1955; Farran, 1928; Fish, 1936; Fuller, 1937; Fuller and Clarke, 1936; Gibbons, 1936; Hardy, 1924, 1926 *c*; Harvey, 1937 *a*; Henderson, 1936; Henderson *et al.*, 1936; Jespersen, 1928, 1932, 1936, 1944; Jørgensen, 1924; Lucas, 1936 *b*; Marshall, Nicolls and Orr, 1939; Marshall and Orr, 1952; Ogilvie, 1934; Rees, 1949; Ruud, 1929; Sanders, 1952; Savage, 1926, 1931, 1937; Wimpenny, 1933, 1936 *a*). These investigations show that the production of *Calanus finmachichus* depends on phytoplankton production, that the herring feed on *Calanus* most intensively in May and June and at that time *Calanus* is present in great abundance and is available to the herring and that the herring landings are related to the presence of *Calanus*. It has been found that abundance of *Calanus* and good landings of herring coincide and scarcity of *Calanus* portends poor landings of the fish. Savage (1937) and Cushing (1955) have clearly brought out the relationship between herring landings and *Calanus* depletion based on the former's feeding habits. Somewhat similar relationships have been found between *Calanus finmachichus* and sei whales, *Balaneoptera borealis* (Hjort and Ruud, 1929) and also between *Euphausia superba* and the blue and fin whales in the Antarctic (Mackintosh, 1934; Hardy and Gunther, 1935).

On the west coast of India as mentioned already, the patch of phytoplankton consisting of mainly *Fragilaria* during the peak period, on most of the occasions, is very extensive. Hence, it may be presumed that, as observed by Cushing in the case of the herring, the oil-sardine shoals scatter to their minimum size before or during the first stages of feeding on *Fragilaria*; and as long as there is an abundance of *Fragilaria* (as during June and July and sometimes August) searching within the patch will be at a minimum and therefore the shoals will be small; the catches of oil-sardine during this period also is small as in the case of the herring in the Shields area. As *Fragilaria* thins out, searching within the patch, now broken into a series of smaller patches (in the early part of the period of bloom, the content of *Fragilaria* in the water is more or less uniform and occurs on almost all days, but later on it is seen on some days only and on other days is absent, probably a result of the breaking up of the patches due to the feeding effect) will increase, and the shoals, no longer dispersed by continuous feeding activity, might also increase in size. Hence, there might be a relation here also, as in the case of the herring, between the length of time, between complete aggregation and complete annihilation, and the subsequent level of the landings. If this period is prolonged there is time for shoals to thicken up as they ' mop up ' the *Fragilaria*. It is possible that here also, the bulk of the fishery is a feeding fishery. The level of landings, therefore, in such a fishery, is directly related to the time for destruction of the *Fragilaria* patch. It may be mentioned that the landings of the oil-sardine are of small magnitude during the beginning of the season perhaps due to the smaller shoals encountered and also, on this coast, due to limitations of fishing operations caused by inclement weather; and, as in the case of the herring, the landings increase later on when the *Fragilaria* patch is almost ' mopped up ' and larger shoals are encountered. The peak of the fishery is attained then when there is apparently no *Fragilaria* in the water. In the period following, it has been found (Nair, 1952) that when *Fragilaria* occurred, oil-sardines were also available on some occasions. It would appear that high landings of oil-sardines is related to an early and rich supply of *Fragilaria* as in 1953.

It is an interesting fact that both sardines and mackerel appear earlier in the south and slowly extend northwards and their disappearance follows a reverse pattern (Panikkar, 1952, p. 765). It was mentioned earlier that the south-west monsoon breaks earlier in the south and the bloom of phytoplankton and zooplankton also begins earlier in the south and spreads north and the current circulation at this time is from the north to south; it is possible that the migration of the fishes at this time is due both to the increasing bloom of plankton, its food, earlier in the south and its spreading north and also their tendency to swim against the flow of current. In the latter period, the current becomes reversed and flows from the south to the north and the bloom of plankton during this period depends more or less on the influx of the Bay of Bengal water into the Arabian Sea and, probably, the intensity of the bloom is greater as one proceeds south; and, the movement of the fishes and their disappearance starting from the north to the south would appear to be correlated with the bloom of plankton and their tendency to move against current. Therefore, the sequence of appearance and disappearance of these fishes may be related to the water movements and plankton bloom; and, it is possible, as observed by Sette (1950, p. 295) that these fishes reach various areas along their route of migration at times, when, on the average, feeding conditions are favourable.

XVI. Magnitude of Fish Production in Comparison with Phytoplankton Production and the Prospects of Future Harvests from the Sea on the West Coast

In the earlier sections of this acount, the magnitude of the standing crop and the interrelationships between phytoplankton on the one hand and nekton on the other have been dealt with. The high fertility of the waters on the west coast of India and the factors governing the production of phytoplankton will be discussed in Part II of this paper. As man has to depend on the fishery resources to partake of the production of organic matter in the sea, itwould be interesting here to assess the magnitude of the total quantity of phytoplankton produced annually in our waters and how it compares with the landings of commercial fishes. The answer should throw some light on the intensity of exploitation going on at present, and whether there is scope for increased exploitation in the future, or whether we are already depleting the stock. The magnitude of plankton production in relation to fishery resources have been reviewed by Riley (1950) and Merriman (1950)

	Author	Region	Method	Production: grams/metre/ square/day wet weight
1.	Atkins (1923)	.. English Channel	CO_2	8·3
2.	Cooper (1933 *b*)	.. English Channel	Various	8·3
3.	Marshall and Orr (1927)	.. Clyde	O_2	26·3
4.	Gran (1927)	.. Bergen	O_2	6·7
5.	Gran (1927)	.. (Culture)	O_2	25·0
6.	Gran (1929 *b*)	.. Ramsdalsfjord	O_2	2·14–9·94
7.	Føyn (1929)	.. Lofoten	O_2	18·6
8.	Seiwell (1935 *a*)	.. Tropical Atlantic	O_2	12·7
9.	Gilson (1937)	.. Arabian Sea	NO_3	14·4

It was not possible here, owing to the limitations of equipment, etc., to estimate production by any of the methods mentioned above. Nevertheless, based on the high nutrient salt content of the water on the west coast,* the high standing crop of plankton noticed in terms of pigment units and dry weight and of zooplankton, etc., and a higher rate of metabolism possible in this tropical environment, it may be assumed that the production of plankton here is very much higher than in some of the temperate regions. The bulk of the producers, the Diatoms, are very much similar in the nature of their composition. The ratio of P: N: Si in the waters of the present region is the same, as in the temperate regions like the English Channel (Part II). The ratio of these elements in the plankton may also be similar as also the mode of intake and assimilation; but, the temperature conditions as well as illumination do not appear to be limiting factors for the maximum production of life in these waters.

Gilson (1937) states that the production in the Arabian Sea calculated by him is of a higher order than in many temperate regions, particularly the English Channel. Gilson's estimation was during a period, as revealed by the present investigation, after the peak of production of phytoplankton had waned. Even then, comparison of the standing crops recorded by him and

* This aspect is discussed in Part II of this account.

in the present area by the writer shows that production is several times higher at the Calicut stations during the same season. Using the C^{14} technique, Steemann Nielsen (1954) found that the production near the mouth of the English Channel to be of the same order of magnitude as estimated by the Plymouth Laboratory from the decline of phosphate values of spring to summer (Atkins, 1923; Cooper, 1933 *b*); considering the period of maximum production of phytoplankton to be from March to June, the value found was 470 milligrams C per square metre per day. In a similar manner, the maximum production recorded by him in the Indian Ocean was 332 milligrams C per square metre per day in a region near the southern end of the Indian Peninsula (Steemann Nielsen, 1952). (The time of the year is not stated.) The above value for the Indian Ocean is stated by the author to be low by 30% and, therefore, the corrected value comes to nearly 432 milligrams, not much different from that found for the Channel during the peak season. The production, when evaluated after considering all the points noted above, for the west coast of India over the continental shelf a wider area of greater depth than that investigated (15 metres), a very highly fertile region, is likely to be several times that found in the English Channel, *at least 6 times* on the average.

For the English Channel, Cooper (1933 *b*, p. 744) has calculated the intensity of phytoplankton production based on the utilization of phosphate, nitrate, silicate, carbon dioxide and oxygen similar to the earlier estimations made by Atkins (1922, 1923). The minimum production calculated by him for an area of 82,100 square kilometres and of 72 metres depth on an average, as per rate of production cited above, was found to be 115 million metric tons annually. The total landings of commercial fish in the English Channel ports in U.K. and French coast in the year 1928 was 71,000 metric tons; the fraction of fish landed to total production of phytoplankton works out to 0·0006 or 0·06% only in an area very intensively exploited by modern methods; probably, that is all what can be obtained as fish out of the total production of matter.

In a similar manner, on the basis of the higher rate of production on the west coast of India (6 times) compared with the Channel, the phytoplankton production may be estimated and correlated to commercial landings. The present area fished on the west coast of India extends approximately 1,200 miles by 7 miles with depth not exceeding 40 metres. The potential fishing area could easily be 1,200 miles by 50 miles (nearly half the width of the continental shelf) equalling 60,000 square miles, *i.e.*, 155,400 square kilometres and to a depth of 100 metres.* Therefore, the production of phytoplankton at the rate mentioned above in an area of 1,55,400 square kilometres amounts to:—

Production in the English Channel = 1,400 metric tons per sq. metre sea surface of depth 72 metres (Cooper, 1933 *b*).

Production of phytoplankton on the west coast of India per sq. metre sea surface of depth 100 metres at 6 times the value of the Channel in 155,400 sq. kilometres

$$= \frac{1{,}400 \times 100 \times 6}{72} \times 1{,}55{,}400$$

$$= 1{,}813{,}000{,}000 \text{ metric tons.}$$

Data available from the statistics of marine fish landings in India show an average catch of 5,61,900 metric tons annually (average of five years landings, 1950–54, based on Central Marine Fisheries Research Station Annual Report, 1955) from the Sea; of this quantity 4,55,900 metric tons, *i.e.*, 80% are landed, on an average, on the west coast. The probability of the west coast being more productive has been indicated by Panikkar (1952, p. 756).

Therefore, the proportion of fish landed on the west coast to phytoplankton production

$$= \frac{4{,}55{,}900}{1{,}813{,}000{,}000} = 0\cdot00002515, \textit{ i.e.,}\ 0\cdot0025\%.$$

This low percentage would indicate that only a small fraction of fish produced appears to be landed assuming that the same proportion of phytoplankton is ultimately converted into fish as in the Channel.

This aspect of the question may now be examined in the light of the results obtained by the *John Murray Expedition* (Gilson, 1937, p. 59) in the Arabian Sea. The value of phytoplankton production calculated amounted to 14·4 grams per metre-square per day for a depth of 55 metres in the open sea. The value was arrived at based on nitrate consumption during a period of five months from *end of September to end of February*. As pointed out in the present account, the bloom of phytoplankton during this period of the year is far less than that during the earlier period, the south-west monsoon,

* In the North Atlantic, according to Riley (1939) phytoplankton can occur up to 400 metres depth; so the basis of 100 metres cannot be an overestimation.

the period of maximum production on this coast. The production of phytoplankton in the region studied by the *Expedition* also, during the south-west monsoon season, is definitely likely to be greater; hence, the value found by the *Expedition* is a very low estimate and, even as such, as pointed out earlier, is of a higher order. Therefore, the surmise made here that, on an average, the production in the present area is likely to be 6 times that of the Channel, is not far wrong, for, nearer the coast on the continental shelf the fertility of waters is also known to be higher (Sverdrup *et al.*, 1942, p. 944) and, on the west coast of India, it is more so for several reasons already dealt with (*see* also Part II). Further, the record of the standing crop of phytoplankton estimated by the *Expedition* is of a far lesser magnitude than that found on this coast. Nevertheless, a comparison of the magnitude of production of phytoplankton at the same rate observed by the *Expedition* and the fish landings may be made. The production at the rate of 14·4 grams per day per square metre for a depth of 55 metres and extent of the fishing area assessed above of 155,400 square kilometres, works out to 820,000,000 metric tons and the proportion of fish landed, 455,900 metric tons, to production of phytoplankton, works out to 0·00005558 or 0·0056%.

In both instances, it is seen that the quantity of fish landed is of a lower magnitude when compared with an intensively exploited area like the English Channel where the percentage of landings works out to 0·06%, nearly 10–30 times the values arrived at for the present area. It may, therefore, be stated that on the west coast of India, a more intensive exploitation of the sea over a wider area within the continental shelf alone is likely to increase the harvest from the sea considerably. " Quite possibly ", as Riley (1950) observes, " the world's fish catch could be increased five or ten times or more". This may possibly apply to the west coast of India also. As Steemann Nielsen (1952, p. 138) states, " the investigation of the production of matter can give valuable information on local possibilities of large-scale fishing".

XVII. SUMMARY

1. A detailed quantitative and qualitative study of the phytoplankton, the main groups comprising the same and the total zooplankton, extending over five years at a station on the south-west coast of India, at Calicut, is reported and the interrelationship between plankton production and fish landings discussed. This is the first time such a detailed investigation lasting over several years has been attempted in a tropical environment and in India in particular.

2. The physical and climatic features of the area is given including particulars relating to ocean currents and sea bottom. It is shown that

Calicut is very much typical of a large extent of the west coast of India and is essentially a tropical environment.

3. The biological year here may be said to commence in the middle of April when the first signs of the oncoming south-west monsoon become evident.

4. Standard methods have been employed in the study of the plankton. Plankton from net samples, particularly vertical hauls, and water samples, have been studied by enumeration, extraction of plant pigments and estimation of dry weight, for making a quantitative and qualitative assessment of the standing crop.

5. The fluctuation of the standing crop in terms of the number of phytoplankton organisms and plant pigment units (Harvey Units) is almost identical. The standing crop of phytoplankton is at its maximum during the south-west monsoon months (May to September–October), attaining the peak in July; from then on falls reaching the minimum in November. There are one or more pulses of production during the north-east monsoon season also (October–November to April).

6. The total quantity of phytoplankton shows variations from year to year depending on the nature of the flora concerned in the blooms.

7. The standing crop during the south-west monsoon is predominantly composed of phytoplankton and during the north-east monsoon season, zooplankton constitutes the bulk of the crop.

8. In terms of dry weight, the fluctuation of the quantity of plankton is not marked by such large oscillations as seen in the former instances. A striking point noticed was that of a close approximation between the ratio of the standing crop during the south-west monsoon season (*bulk* of phytoplankton) and the north-east monsoon season (*bulk* of zooplankton). The ratio was found to be 1 : 0·9, and it is surmised that the quantity of living matter that a mass of water can support, the *biomass*, is in equilibrium irrespective of the nature of the constituents, plant or animal.

9. The magnitude of the standing crop in terms of the number of organisms, plant pigment units and quantity of carbon, in a unit volume of water, is shown and compared with similar observations from several regions in the tropical, temperate and Arctic waters. It is seen that the standing crop in the present area is of a very high order and the area is one of the most fertile regions of the world for phytoplankton production.

10. Some particulars are given relating to the horizontal and vertical distribution of the phyto- and zoo-plankton.

11. The phytoplankton is composed of mainly by the Bacillariophyceæ (Diatoms); the Dinophyceæ, Cyanophyceæ, Silicoflagellatæ and Coccolithineæ occur next in the order mentioned. The Bacillariophyceæ constitute the *bulk* of phytoplankton throughtout except on rare occasions when the phenomenon of "discoloured water" occurs owing to the dominance of a single organism in the water to the total exclusion of others.

12. The seasonal fluctuation of the Bacillariophyceæ follow closely that of total phytoplankton outlined above as they form the bulk of the flora.

13. The Dinophyceæ also have a peak during the south-west monsoon season, in June or July, and one or more peaks of production during the north-east monsoon season.

14. The Cyanophyceæ (Myxophyceæ) attain the maximum development during the north-east monsoon season in the warmer months. The other groups occur sporadically during the year.

15. The total number of zooplankters increases with the increase of the Diatoms. The zooplankton composed of smaller forms shows a peak in August, during the south-west monsoon season, immediately after the peak of the phytoplankton. During the next season there are one or two pulses of development composed mainly of larger forms.

16. The phenomena of "discoloured water" observed are described briefly.

17. The seasonal fluctuation of phytoplankton and zooplankton is compared with the earlier observations in India and elsewhere and discussed.

18. The phytoplankton-zooplankton relationship observed here is described and discussed with data from other localities.

19. The relationship between commercial fish landings, and phyto- and zooplankton standing crop is indicated. A close relationship was found between the standing crop of phyto- and zoo-plankton with the total quantity of fish landed, particularly with the landings of the oil-sardine and the Indian mackerel, which are plankton feeders. An intimate relationship appears to exist between the oil-sardine and the Diatom *Fragilaria oceanica*, which occurs in large quantities during the south-west monsoon season, and this relationship is discussed.

20. The magnitude of the phytoplankton production on the west coast of India has been tentatively estimated and contrasted with the total landings of commercial fish on the west coast. It is found that the fish landed represents only a very small fraction of the total production of phytoplankton, and compared with an intensively exploited area like the English Channel, it is pointed out that there is vast scope for increased exploitation with positive results on the west coast of India.

(Literature and Acknowledgement at the end of Part II)