A STUDY OF THE SEASONAL CHANGES IN THE DISSOLVED OXYGEN OF THE SURFACE WATERS OF THE SEA ON THE MALABAR COAST

BY L. R. KASTURIRANGAN*

(Central Marine Fisheries Research Sub-Station, Calicut, Malabar)

INTRODUCTION

There is wide recognition at the present day of the importance of hydrographical investigations, particularly in association with biological studies of the marine environment. A knowledge of the physics and chemistry of sea-water is essential for a scientific approach to the fundamental problem of organic production in the sea and, in certain instances, greatly helps in the solution of specific problems connected with fisheries. Investigations on the distribution and seasonal variations of temperature, salinity, dissolved oxygen, pH and of various inorganic compounds of phosphorus, nitrogen and silicon, —usually referred to as " nutrient salts,"—have been carried out in many countries abroad largely in temperate latitudes (Harvey, 1945). Work in tropical waters has not been on the same scale and most of it is of recent date. Studies carried out in India and Australia would be found in the publications of Sewell (1925–32), Orr (1933), Dakin and Colefax (1935), Thompson and Gilson (1937), Bal *et al.*, (1951), Chidambaram *et al.* (1951, 1954), Jayaraman (1951, 1954), Prasad (1952) and Ramamurthy (1953, 1953 *a*). In regard particularly to dissolved oxygen, mention may be made of the attempts of Cooper (1933) and others to derive an index of organic productivity of an area from values of oxygen production and consumption. " In nature, the oxygen accumulates in the layers of organic production and thus its fluctuations in time and space give a measure of the intensity of phytoplankton outbursts. It can provide only minimal values because the exact quantity of oyxgen produced is obscured by the respiratory activity of animals and bacteria, and in case of surface supersaturation some oxygen is given off to the atmosphere" (Sverdrup *et al.*, 1942, p. 934). The above quotation makes evident the usefulness of oxygen values when they are available in required detail. A simple series of values derived from analysis of surface samples such as is presented below, has interest from another angle revealing

* Present address: Prawn Research Unit of the Central Marine Fisheries Research Station, Ernakulam, Kerala.

as it does the broad features of the changes in composition of the sea-water from season to season and year to year.

The data on dissolved oxygen presented and discussed in this paper, are part results of a scheme of water analysis which was carried on at the Central Marine Fisheries Research Sub-Station at Calicut as a useful auxiliary to investigations on fisheries. The oxygen estimations were the work of the present author, analysis of other constituents being carried out by different workers.

MATERIAL AND METHODS

The sea-water samples for analysis of dissolved oxygen were collected from two stations located due west of West Hill, Calicut. Station I was two to three miles off the coast where the depth was approximately eight fathoms. Station II was six to eight miles off the coast in an area approximately twenty fathoms in depth. The stations were reached in a row boat (country craft) employed for the collection of plankton. The water samples were taken from surface waters at about 7 a.m. (Station I) and 10 a.m. (Station II). They were brought to the laboratory in glass-stoppered bottles of 200 ml. capacity, provided with black cloth-jackets to shield the water from the action of sunlight and prevent photosynthetic activity in the diatoms contained in the water that might otherwise affect the value of the dissolved oxygen. The bottle was completely filled leaving no air space above the water when being stoppered; other necessary precautions were also observed. The samples were treated immediately on arrival at the laboratory, but some lapse of time was unavoidable between the moment of collection and the moment of fixation. It is to be expected that during this interval of time, the respiratory activity of the bacteria and planktonic organisms included in the water samples would have affected the concentration of dissolved oxygen and introduced an element of error into the titration values. It is supposed that this error was relatively small. The dissolved oxygen was estimated by Winkler's titration method (Harvey, 1928). The values in millilitres per litre of water were recorded as well as the percentage saturation calculated with the aid of Fox's formula. Over 500 estimations were obtained covering a continuous period of four years; but of these, the values for only 444 samples are presented here, including 347 samples from station I and 97 samples from station II. The latter are conveniently referred to as the offshore series although it is realized that the boundary between the inshore and the offshore regions cannot be very strictly defined. Owing to the rough seas and adverse winds, offshore water samples could not be collected during the monsoon months of June to September and the data cover only eight months in each year. Though incomplete, the offshore series of data is useful for comparison with the inshore series and materially helps to define the picture obtained of the conditions and hence is included here. The salinity titrations were performed according to the simplified method of Oxner and Knudsen using 10 ml. samples. Fuller details of these determinations will be found in George (1953).

Results

The observed values of temperature, salinity, and dissolved oxygen are given as monthly averages in Tables I, II and III together with rainfall data for Calicut obtained from the daily weather reports of the Regional Meteorological Centre, Madras; these values are represented graphically in Text-Figs. 1, 2 and 3. The second column in the tables gives the total number of observations taken in the month from which the monthly average was computed.

(*i*) *Temperature and salinity.*—The temperature of the sea-water shows a range of 5·45° C. For complete series, from the lowest value of 24·85° C. in August 1951 to the highest value, 30·30° C. in April 1952. The highest value of the year is met with in April or May, just before the outbreak of the south-west monsoon, and the lowest value in June, July or August, in the thick of the rainy season. A review of the individual observations within any month shows that the least range of variation, usually 1° C. or less, is found in the months, November to the succeeding March, and the widest fluctuations, up to 4·5° C., in June, July or August. The mean monthly values of salinity show a range of 10·32‰, from the lowest value of 25·38‰ in August 1952 to the highest, 35·70‰ in May 1951. The highest salinity of a year is found in the month of May (or April) and the lowest in the succeeding July (or August) when the brunt of the monsoon rains is past. Comparison of individual values of a month shows that the narrowest variations (0·4 to 1·0‰) occur in January, February or March and the widest variations (10·0 to 20·0‰) in June, July or August at the height of the south-west monsoon. It is evident, therefore, that changes in salinity and temperature keep in step with each other, not only in the broad trend revealed by the shifts in the mean monthly values, but in the steadiness or fluctuations of the individual values within any month, and that both are closely related to rainfall. Accordingly, in Text-Figs. 1, 2 and 3 we find that the curves for temperature and salinity correspond closely, rising or falling together, more or less. Further, it is seen that the annual cycle includes two distinct phases, the first phase being one of a steep fall in May, June, July, contemporary with the heaviest rains of the south-west monsoon, and the second phase, one of a gradual and fluctuating rise from July to August to the succeeding April to May. This second phase includes two sub-phases. The first sub-phase covers the period July to November exhibiting a comparatively steeper rise of salinity and temperature, whereas the second sub-phase, November to May, is much less steep. When November shows a distinct secondary peak as in 1949 or 1952, it is followed by a shallow trough in January to February before the advent of the primary peak in May. In 1950, neither the November peak nor the January to February trough are at all distinct whereas in 1951, although both the peak and the trough are present, the temperature curve is not in step with the salinity curve. The vagaries of the second phase of the curves are perhaps to be correlated with the erratic character of the north-east monsoon rains in the four years under review.

(*ii*) *Oxygen.*—The values for oxygen are depicted in the graphs both as ml./L and as percentages of saturation. The 100% saturation level is also shown as a horizontal line for ready location of supersaturation "peaks" in the graphs. It will be noticed that the percentage curve closely follows the millilitre curve and a point of minor interest is that the two curves approximate to each other when temperature values are high and move widest apart when temperature values are low.†

The values of dissolved oxygen vary from 3·01 ml./L in September 1952, to 6·45 ml./L in July 1950 with a range of 3·44 ml./L. These variations cover a wider range on the west coast than on the east coast, as may be seen from Table IV. It will also be seen from Tables I, II and III that supersaturation values are met with quite frequently, occurring on no less than twelve months out of forty-seven in the inshore series and nineteen out of thirty months in the offshore series. The average value for the entire period studied is 4·22 ml./L which is higher than the average values observed at Madras (4·03 ml./L) and Mandapam (Gulf of Mannar, 3·90 ml./L; Palk Bay, 3·21 ml./L).

The features of the oxygen graph may be broadly summarised as follows: (1) A gradual fall in value from November to the following May is clearly seen in 1950–51, 1951–52 and 1952–53, in the inshore series (Figs. 1 and 2) as well as in the offshore series (Fig. 3). The fall in the oxygen graph corresponds to a gradual rise in the curves for temperature and salinity and implies some degree of inverse correlation. (2) The lowest value of the year is located in September in all the years and the highest value in November (except in 1950 when the November value is the second highest) and a rapid rise in the curve occurs during September-October-November. (3) The curve for the period, May to September, which includes the monsoon months and the following ones, shows no uniform characteristics for the four years which have been studied. In 1950, the curve shows a very prominent peak, indeed the most prominent in the entire stretch. In 1951, on the other hand,

† When the temperature is high, the saturation volume is low and so the percentage saturation figure is relatively high. An increase in the percentage saturation figure automatically raises the graph line and brings it closer to the line above it which is the millilitre line.

TABLE I

Inshore series of water samples

Month	No. of observations	Rainfall in inches (Total)	Temperature °C. (mean)	Salinity ‰ (mean)	Dissolved Oxygen	
					ml./L. (mean)	Percentage saturation (average)
1949						
October ..	9	8·3	26·6	32·24	3·61	74·00
November ..	8	1·6	28·6	35·59	4·35	93·01
December ..	9	0·0	27·6	34·43	4·31	91·39
1950						
January ..	9	0·0	27·4	33·95	5·20	109·52
February ..	8	1·1	27·9	34·08	5·03	107·59
March ..	9	0·1	29·2	35·39	4·57	101·03
April ..	8	0·9	30·0	36·04	4·68	104·78
May ..	9	13·6	29·0	35·26	4·84	106·19
June ..	9	28·3	26·7	31·64	4·45	91·05
July ..	5	38·1	25·0	27·24	6·45	124·79
August ..	8	15·2	25·1	27·63	5·47	111·18
September ..	8	18·5	25·0	32·70	4·25	85·32
October ..	9	10·1	27·2	31·95	5·21	107·81
November ..	8	3·0	27·8	33·87	5·57	117·70
December ..	7	0·0	27·5	33·94	4·66	98·60
1951						
January ..	9	0·0	27·8	33·81	4·45	94·74
February ..	8	0·4	28·3	34·46	4·54	97·81
March ..	9	0·0	29·1	34·95	4·00	87·24
April ..	9	3·6	29·0	34·80	3·99	86·65
May ..	8	5·9	29·6	35·70	4·19	92·87
June ..	4	37·1	27·4	31·40	3·96	81·38
July ..	7	27·3	25·2	29·57	3·74	73·71
August ..	8	7·4	24·85	32·24	2·27	85·30
September ..	4	7·4	26·2	34·00	3·15	65·53

TABLE II

Inshore series of water samples (Continued)

Month	No. of observations	Rainfall in inches (Total)	Temperature °C. (mean)	Salinity ‰ (mean)	Dissolved Oxygen	
					ml./L. (mean)	Percentage saturation (average)
1951						
October ..	6	5·6	29·1	32·09	4·84	103·72
November ..	8	6·6	29·5	32·23	4·94	105·22
December ..	8	3·8	28·15	34·02	4·18	89·28
1952						
January ..	7	0·0	27·9	34·55	4·23	90·22
February ..	8	0·1	28·7	34·47	4·44	96·23
March ..	9	0·3	29·5	34·60	4·19	92·13
April ..	8	2·9	30·3	34·60	4·27	95·20
May ..	8	6·8	29·4	34·95	3·70	79·46
June ..	3	31·3	28·1	32·00	4·30	86·61
July ..	5	17·7	24·9	32·75	3·74	74·98
August ..	8	14·1	25·0	25·38	4·48	85·75
September ..	8	0·5	24·9	29·52	3·01	58·48
October ..	5	15·9	26·3	31·50	3·64	73·79
November ..	4	0·1	27·9	34·51	4·88	104·02
December ..	7	2·6	28·3	33·24	4·27	90·93
1953						
January ..	9	0·0	28·4	31·86	4·20	89·12
February ..	8	0·8	28·5	32·22	4·34	92·20
March ..	9	0·2	29·4	34·50	3·64	79·53
April ..	6	4·0	29·8	35·00	3·98	86·80
May ..	8	1·0	28·45	35·55	3·38	73·88
June ..	6	18·1	27·32	33·90	3·89	82·03
July ..	4	47·3	26·9	25·50	4·70	93·77
August ..	3	10·1	26·0	28·70	5·34	99·62

TABLE III

Offshore series of water samples

Month	No. of observations	Rainfall in inches (Total)	Temperature °C. (mean)	Salinity ‰ (mean)	Dissolved Oxygen ml./L. (mean)	Dissolved Oxygen Percentage saturation (average)
1949–50						
October ..	4	8·3	26·60	32·90	3·84	78·80
November ..	5	1·6	28·60	33·42	4·71	101·54
December ..	4	0·0	28·45	34·17	4·63	99·50
January ..	4	0·0	27·95	33·65	4·96	105·75
February ..	4	1·1	28·80	34·23	5·58	118·87
March ..	5	0·1	29·64	35·09	4·78	105·73
April ..	4	0·9	30·10	35·78	4·85	108·80
May ..	4	13·6	29·90	35·54	5·76	129·01
1950–51						
November ..	1	3·0	28·60	32·63	6·42	137·76
December ..	2	0·0	28·40	34·12	5·05	108·63
January ..	2	0·0	28·20	33·70	4·82	103·78
February ..	2	0·4	28·70	34·40	4·82	103·81
March ..	2	0·0	29·30	34·50	5·45	109·65
April ..	2	3·6	30·20	35·00	4·47	98·86
May ..	1	5·9	30·00	35·30	4·65	103·56
1951–52						
October ..	1	5·6	29·40	32·07	5·51	118·24
November ..	4	6·6	29·40	31·44	5·22	112·95
December ..	4	3·8	28·40	34·02	4·28	92·33
January ..	4	0·0	28·10	34·56	4·64	99·38
February ..	4	0·1	29·00	34·34	4·67	101·58
March ..	4	0·3	29·50	34·90	4·57	100·72
April ..	5	2·9	30·50	34·40	4·54	101·09
1952–53						
October ..	1	15·9	26·00	33·20	6·84	139·00
November ..	2	0·1	28·30	34·60	5·90	127·43
December ..	4	2·6	28·00	33·62	4·28	90·65
January ..	4	0·0	28·25	31·60	4·48	94·34
February ..	4	0·8	28·60	32·19	4·54	93·96
March ..	4	0·2	29·50	34·25	4·18	89·58
April ..	4	4·0	29·30	34·95	4·28	93·46
May ..	2	1·0	28·70	35·20	4·27	92·05

the curve remains very low and much below saturation level. In 1952, the curve oscillates up and down a little below saturation level. In 1953, it shows a steady rise towards a peak, touching saturation level in August but it is not comparable to the prominent peak of July 1950. (4) The period November to May of 1949–50 shows, on the whole, a rising trend of oxygen values that is contrasted with the falling trend of this period in the other three years. This feature is to be observed not only in the inshore series (Figs. 1 and 2) but also in the offshore series (Fig. 3). Hence, it may be inferred that the variant

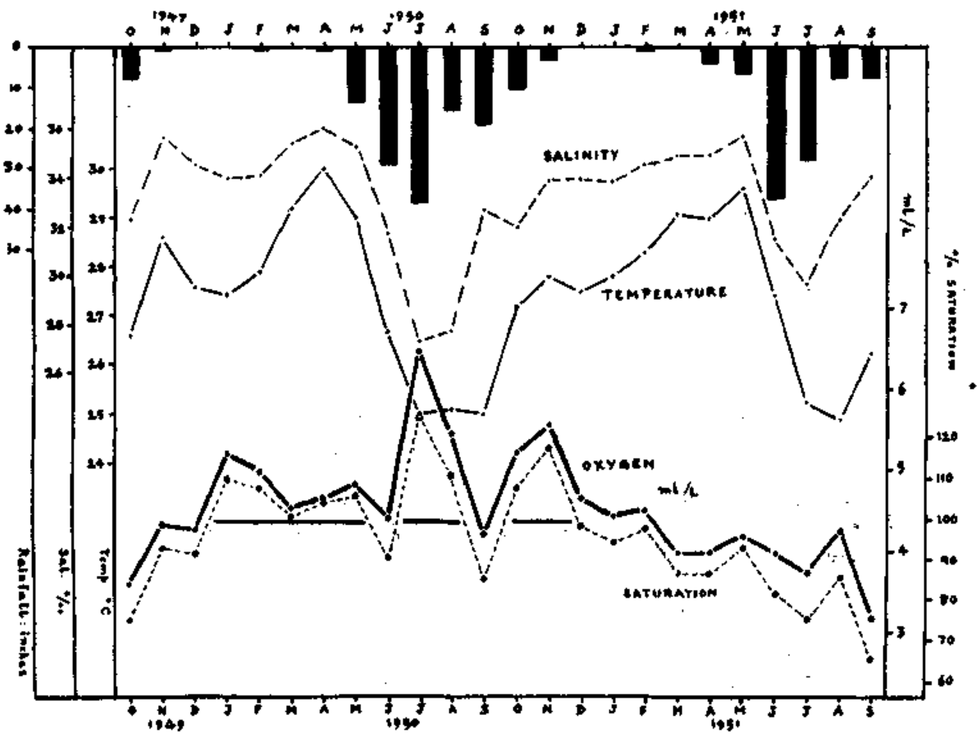

Fig. 1. Monthly distribution of average values of dissolved oxygen, etc., for inshore series of water samples during 1949–51.

observations were not the result of some purely local changes in the inshore waters in these months, but arose out of conditions spread over a wide area during this period of 1949–50. Although this period shows a generally rising trend, the highest value of the period is not at the end in May but in January in the inshore series and in February in the offshore series. (5) Supersaturation is a prominent feature in 1949–50 and 1950–51 but it is much less prominent in 1951–52 and hardly in evidence in 1952–53. This feature is as clear in the offshore series as in the inshore series (Fig. 3). (6) Supersaturation seems to be more generally prevalent in the offshore region than in the

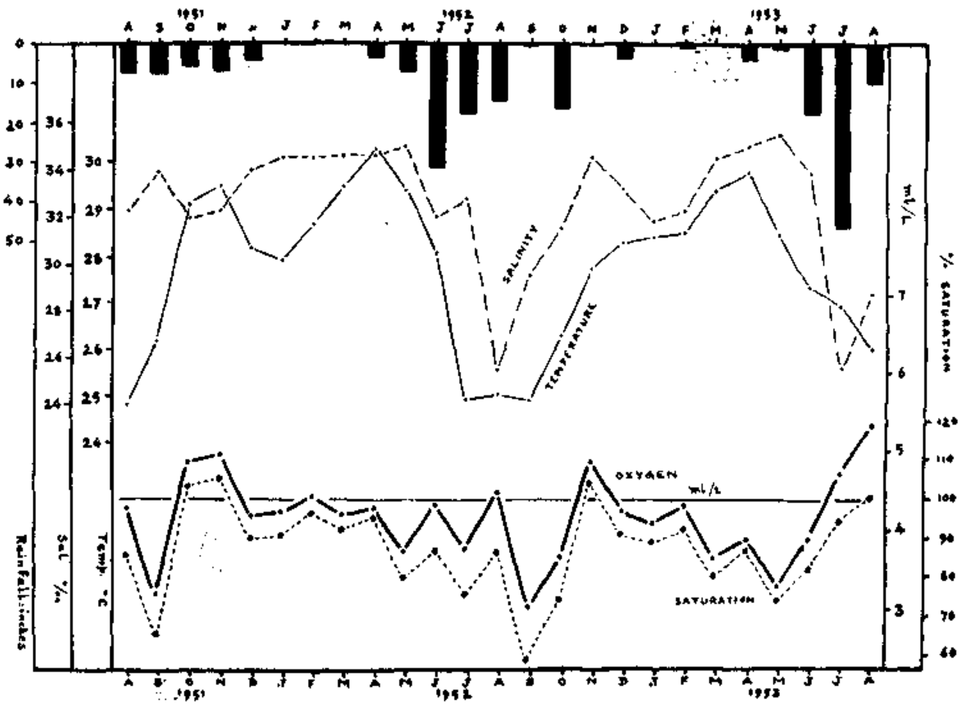

FIG. 2. Monthly distribution of average values of dissolved oxygen, etc., for inshore series of water samples during 1951-53.

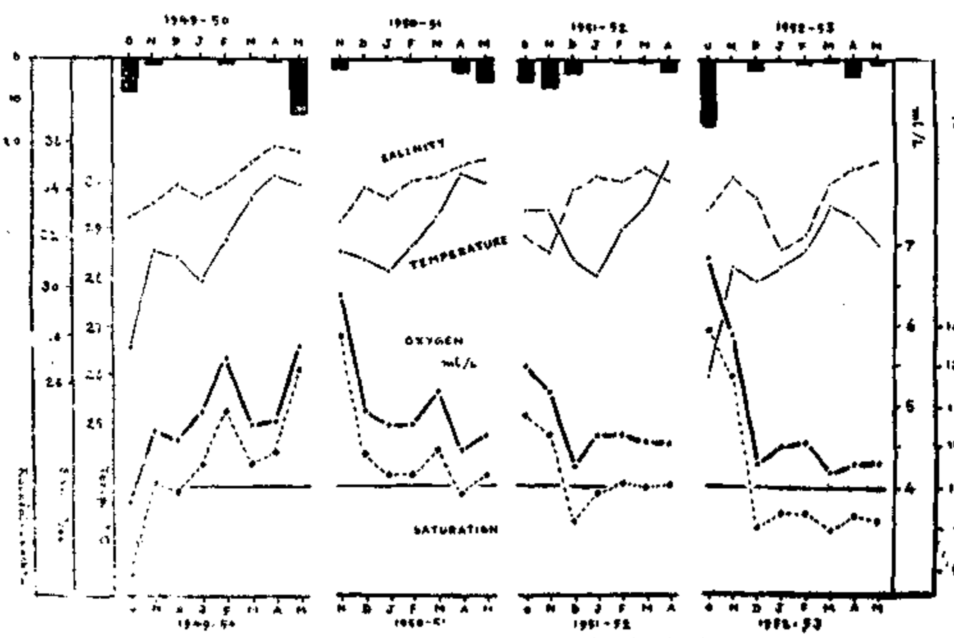

FIG. 3. Monthly distribution of average values of dissolved oxygen, etc., for offshore series of water samples during 1949-53.

inshore region. In the former it was observed in nineteen instances out of thirty (Table III) whereas in the inshore region it was noticed in twelve months out of forty-nine.

Discussion

As a preliminary to the discussion which follows, some reference to certain general features of the Malabar coast is necessary and they are briefly reviewed here. More detailed accounts would be found in Seshappa (1953), Bristow (1938) and du Cane *et al.* (1938). (*a*) The west coast of India has a much higher annual rainfall than the east coast. The annual normal is 121 inches at Calicut as against 50 inches at Madras. This rain is concentrated in the months of June and July which receive the brunt of the south-west monsoon. The north-east monsoon which provides the principal rains on the east coast in the months October and November, is feeble on west coast and was hardly in evidence in 1949–53. (*b*) There are three rivers in the vicinity of Calicut, the Elattur (or Korapuzha), Kallayi and Beypore rivers, that bring considerable quantities of fresh-water in the aggregate into the sea. (*c*) Mud bank formation is a regular feature of the Malabar coast at various points and a mud flat makes its appearance opposite West Hill in most years. The rough seas of the monsoon months and the attendant disturbances of the sea bottom lead to the elevation of the mud bank so that it is plainly visible above the general water level. This happens during the monsoon months in most of the years but sooner or later it undergoes dissolution and is lost to view. During the period of its existence, the sea is calm between it and the shore even though rough seas and heavy surf are prevalent in neighbouring areas. Station I mentioned earlier, lies in area that is further to seaward than the mud bank but the waters of this region are quite possibly influenced by the disturbances of the mud bank area. (*d*) The next important feature of the Malabar coast is the occurrence of repeated blooming of phytoplankton during the south-west monsoon period. Although the density of the annual production may vary from year to year, within any particular year, the heaviest blooms usually occur in June and July. Blooming occurs at varying intervals in the following months also, but seldom approaches the monsoon crops in density. These remarks are based on general observations on plankton made by the present author and they would be found to be in broad agreement with published accounts (George, 1953; Hornell and Nayudu, 1923). (*e*) The last feature to be noticed is the occurrence of coastwise currents. That such currents occur and that they undergo periodical reversal of direction according to the season of the year, is common knowledge among the fisherfolk; but precise information is lacking as to the direction, velocity, distance from the shore, depth to which the current is effective and similar aspects. In the absence of such precise information the probable effects of the currents on the composition of water samples from Stations I and II must remain problematical.

The main features of the graphs for temperature and salinity have been pointed out earlier. The steep fall in June, July and August, referred to as the first phase, is no doubt to be attributed to the heavy rains. At the height of the monsoon, a considerable volume of fresh-water must be brought into the sea by precipitation and run off from land, and the effects of this addition are further accentuated by the discharge of the three rivers referred to earlier. Since the rainfall on the west coast is much greater than on the east coast the minimum values—of monthly means—are seen to sink lower at Calicut than at Madras or at Mandapam (Table IV).

TABLE IV

Minimum and maximum values at Calicut compared with values at Madras and Mandapam

		Calicut	Madras (Ramamurthy, 1953)	Mandapam (Jayaraman, 1954)	
				Gulf of Mannar	Palk Bay
Temperature °C.	Minimum	24·85	27·30		
	Maximum	30·30	30·10		
	Range	5·45	2·80		
Salinity ‰ ..	Minimum	25·38	26·24	27·47	27·25
	Maximum	35·70	34·94	36·47	36·39
	Range	10·32	8·70	9·00	9·14
Oxygen: ml./L.	Minimum	3·01	3·815	3·34	1·70
	Maximum	6·45	4·373	4·59	4·40
	Range	3·44	0·558	1·25	2·70
Oxygen: Percentage saturation	Minimum	58·48	83·37		
	Maximum	124·79	89·35		
	Range	66·31	5·98		

The features of the oxygen graph may now be considered in relation to the probable determining factors. (1) The gradual fall in the curve from November to the succeeding May is found in all the four years. It shows an inverse correlation with the curves for salinity and temperature which is not surprising in view of the known greater solubility of oxygen in water at lower temperature and salinity (Redfield, 1948). Since the period is one of diminishing phytoplankton production (and therefore diminishing liberation of oxygen through photosynthesis) and increasing zooplankton (and therefore increasing respiratory consumption of oxygen), the falling trend is readily explicable. An increase of oxygen values simultaneous with diatom outbursts was observed by Cooper (1933) and has since been corroborated by others (Marshall and Orr, 1927; 1930; Riley, 1941). (2) The steady rise in the curve from September to November is also quite clearly apparent in all the four years. It shows a positive correlation with temperature and salinity which is against expectation. The location of the lowest value of the year in September is particularly noteworthy. It should be recalled that this is the very centre of the main fishing season of the year (Chidambaram and Menon, 1945); the first big zooplankton maximum of the year also occurs at this time, the plankton being dominated by copepods, crustacean larvæ, polychætes and other edible constituents figuring in the diet of the shoaling fishes. A marked lull in phytoplankton production simultaneous with the zooplankton maximum could possibly account for the occurrence of the lowest oxygen value in September in all the four years. Even so, the reasons for the subsequent rise in the values and the occurrence of a peak in November are not altogether clear. Phytoplankton blooms are far from characteristic of this period of the year and secondary peaks of the annual cycle seem to occur in December or January (George, 1953, p. 92). (3) The great diversity of behaviour exhibited by the oxygen curve in the period May to September is puzzling. Nevertheless it seems possible that the occurrence of a peak in the monsoon months, contemporary with the phytoplankton outbursts, such as we find in 1950, is the condition to expect in all the years. The steady rise of the curve seen in June, July and August, 1953 also supports this view. If this be so, the absence of a peak in 1951 and 1952 requires explanation. It does not appear that diatom blooms were markedly deficient in these two years (George, 1953). Of the various factors listed earlier, the two which seem most likely to be involved in this connection are, firstly, the mud banks and secondly the coastwise currents. Of the second our present knowledge is too limited to be of any assistance. In regard to the mud bank it may be said that it seems to exercise an effect on the neighbouring waters in the direction of reduced oxygen. It probably does this in two ways. Firstly, by moderating wave action and turbulence it lowers the rate of solution of atmospheric oxygen in water and secondly, by releasing materials into the water which promote oxidative processes and thus tending to deplete the oxygen dissolved in the water. That the surface layers of sediments have an oxygen deficit and tend to absorb oxygen is a known fact (Sverdrup *et al.*, 1942,

p. 997). When the mud flat is close to the shore as in 1950 (Seshappa, 1953, p. 274) it is further away from Station I and less effective in lowering oxygen values of that area. When the mud flat is away from the shore as presumably in 1951 and 1952, its effects are more pronounced on Station I and reflected in lowered oxygen values. While the mud bank is certainly not the only important factor in the situation, it is not a factor to be dismissed as of negligible account.* (4) The rising trend of oxygen values in November to May 1949–50 which is the opposite of the trend in the following years, cannot be explained on the basis of known data on other factors. It is tempting to suppose that in 1949, the November peak was delayed by two months and occurred in January 1950 (inshore series) or February 1950 (offshore series) thereby shortening the succeeding span of the falling trend. But such a supposition in no way throws light on the factors causing the postponement. Data on phytoplankton production, in terms of Harvey's pigment units, have been gathered for these years (Subrahmanyan, unpublished) and when published might throw some revealing light on these puzzling features. (5) The occurrence of supersaturation in 1949–50 and 1950–51 and its diminution in the next two years and (6) the greater prevalence of supersaturation in offshore waters, are features not readily understandable at present and, as in the case of the preceding feature, they might eventually be found to be related to the phytoplankton cycle in the different years, 1949–53.

The view has been expressed (Thompson and Gilson, 1937; Riley, 1939; Smith *et al.*, 1950) that supersaturation is not common in tropical waters. At Madras supersaturation was not observed in any of the fifteen months of the investigation (Ramamurthy, 1953) and at Mandapam " the oxygen values are far below the saturation limit " (Jayaraman, 1954, p. 363). The present study, however, has shown that numerous instances of supersaturation occurred during the period of four years, usually in the months characterized by the greatest phytoplankton activity. The occurrence of supersaturation might very well be related to the greater intensity of production of diatoms in the neritic waters of the Malabar coast as compared to the east coast of India.

The hazards of formulating generalizations on the basis of data covering a few months or just one year are well known and need no elaboration here.

* One word of caution is necessary at this point. It was said earlier that turbulent seas and powerful water movements lead to the emergence of the mud bank and cause its eventual dissolution. While this is undoubtedly true, it is also true to say that stagnant water overlies and surrounds a mud bank for much of its duration. The inconsistency is only apparent. The stagnant conditions obtain in the superficial layers of the sea and for intermittent periods. The turbulent conditions, on the other hand, are active in the deeper levels and they, too, abate periodically. When active, their effect is either to elevate the mud bank still further, or to wear it down.

By increasing the span to four years it was expected that these hazards would be reduced and that the annual cycle would emerge into greater clarity. The second expectation, however, has been only partially fulfilled. While certain salient features of a recognizably periodic character are evident, there are other features which show no annual periodicity and which for the present must remain obscure.

SUMMARY

1. The dissolved oxygen content of the surface waters of the sea in offshore and inshore regions near Calicut was studied during 1949 to 1953. The data on oxygen are presented along with data on temperature; salinity and rainfall are discussed in relation to the physical and biological characteristics of the Malabar coast.

2. The salinity graph closely follows the temperature graph and these two together are in inverse relation with the oxygen graph particularly in the period November to May.

3. The oxygen graph shows three main features, (*a*) a gradual fall from November to the succeeding May, (*b*) a rise from September to November, and (*c*) rather diversified behaviour during June, July, August, which includes, when peak values appear at all, the occurrence of the biggest peak of the year.

4. The south-west monsoon exercises a profound influence on various factors in the environment including the oxygen content of the water. High phytoplankton production during the monsoon months of June, July and August seems to be directly correlated with high oxygen values, although in many years the latter effect may be almost wholly masked by other and opposite influences.

5. Unstable conditions characterized by wide fluctuations in values prevail during June, July, August and relatively stable conditions during the following January, February, March, the intervening months being transitional in character.

6. Supersaturation values are of frequent occurrence in the inshore areas particularly in periods of phytoplankton dominance; they are even more frequently recorded from offshore areas.

ACKNOWLEDGEMENTS

The author wishes to express his grateful thanks to Dr. N. K. Panikkar and Dr. B. S. Bhimachar for their interest in the work and helpful suggestions. Grateful acknowledgement is due to Mr. P. C. George for the data on salinity and temperature which are taken from the records of the sub-station maintained by him.

REFERENCES

Bal, D. V., Pradhan, L. B. & Gupte, K. G. 1946 — A preliminary record of some of the chemical and physical conditions of the Bombay Harbour during 1944–45. *Proc. Indian Acad. Sci.*, **24 B**, 60–73.

Bristow, R. C. 1938 .. *History of Mud Banks*, Vols. I and II. Ernakulam, Cochin Government Press.

Chidambaram, K., Isaac Rajendran, A. D. & Valsan, A. P. 1951 Certain observations on the hydrography and biology of the Pearl Bank, Tholayiram Paar, off Tuticorin in the Gulf of Mannar in April 1949. *J. Madras Univ.*, **21 B**, 48–74.

—— & Menon, M.D. 1945 The co-relation of the west coast (Malabar and South Canara) Fisheries with plankton and certain oceanographical factors. *Proc. Indian Acad. Sci.*, **22 B**, 355–67.

Cooper, L. H. N. 1933 .. Chemical constituents of biological importance in the English Channel. November 1930 to January 1932. Part II. Hydrogen-ion concentration, excess base, carbon dioxide and oxygen. *J. mar. biol. Ass., U.K.*, **18**, 729–53.

Dakin, W. J. & Colefax, A. N. 1935 Observations on the seasonal changes in temperature, salinity, phosphates and nitrates, nitrogen and oxygen of the ocean waters of the continental shelf of New South Wales and the relationship to plankton production. *Proc. Linn. Soc.*, N.S.W., **60**, 303–14.

du Cane, C. G., Bristow, R. C., Coggin Brown, C. & Keen, B. A. 1938 *Report of the Special Committee on the Movements of Mud Banks*, Cochin, 1–57.

George, P. C. 1953 .. The marine plankton of the coastal waters of Calicut with observations on the hydrological conditions. *J. Zool. Soc., India*, **5**, 76–107.

Harvey, H. W. 1928 .. *Biological Chemistry and Physics of Sea-Water*. Cambridge University Press.

————. 1945 .. *Recent Advances in the Chemistry and Physics of Sea-Water*, Cambridge University Press.

Hornell, J. & Ramaswami Naidu, M. 1923 A contribution to the life-history of the Indian sardine with notes on the plankton of the Malabar Coast. *Madras Fish. Bull.*, **17**, 129–97.

Jayaraman, R. 1951 .. Observations on the chemistry of the waters of the Bay of Bengal off Madras City during 1948–49. *Proc. Indian Acad. Sci.*, **33 B**, 92–99.

————. 1954 .. Seasonal variations in salinity, dissolved oxygen and nutrient salts in the inshore waters of the Gulf of Mannar and Palk Bay near Mandapam (S. India). *Indian J. Fish.*, **1**, 345–364.

Marshall, S. M. & Orr, A. P. 1927 The relation of the plankton to some chemical and physical factors of the Clyde Sea area. *J. mar. biol. Ass., U.K.*, **14**, 837–68.

————. 1930 .. A study of the spring diatom increase in Loch Striven. *Ibid.*, **16**, 853–78.

Orr, A. P. 1933 .. Physical and Chemical conditions in the sea in the neighbourhood of the Great Barrier Reef. *Sci. rep. Great Barrier Reef exped.*, 1928–29, **2**, No. 3.

Prasad, R. R. 1952 .. Preliminary observations on the temperature gradients and light penetration in the upper 200 feet of water of the Bay of Bengal. *Proc. Indian Acad. Sci.*, **36 A**, 61–69.

Ramamurthy, S. 1953 .. Seasonal changes in the Hydrogen-ion concentration and the dissolved oxygen content of the surface waters of the Madras Coast. *J. Madras Univ.*, **23 B**, 52–60.

———. 1953 *a* .. Hydrobiological studies in the Madras coastal waters. *Ibid.*, **23 B**, 148–63.

Redfield, A. C. 1948 .. The exchange of oxygen across the sea surface. *J. Mar. Res.*, **7**, 347–61.

Riley, G. A. 1939 .. Plankton studies, II. The Western North Atlantic, May–June, 1939. *Ibid.*, **2**, 145–62.

———. 1941 .. Plankton studies, III. Long Island Sound. *Bull. Bingham Oceanogra. Collection*, **7**, 1–23.

Seshappa, G. 1953 .. Observations on the physical and biological features of the inshore sea bottom along the Malabar coast. *Proc. nat. Inst. Sci., India*, **19**, 257–79.

Smith, F. G. W., Williams, R. H. & Davis, C. C. 1950 An ecological survey of the subtropical inshore waters adjacent to Miami. *Ecology*, **31**, 119–46.

Sverdrup, H. U., Johnson, M. W. & Fleming, R. H. 1942 *The Oceans, their Physics, Chemistry and General Biology.* New York, Prentice-Hall, Inc.

Thompson, E. F. & Gilson, H. C. 1937 Chemical and Physical investigations. *John Murray Exped. Sci. Rep.*, **2**, No. 2.