J. Mar. biol. Ass. India, 1962, 4 (1) : 23-43

STUDIES ON DIURNAL VARIATIONS IN THE HYDROBIOLOGICAL CONDITIONS OFF THE WALTAIR COAST

By T. S. SATYANARAYANA RAO & V. CHALAPATI RAO
(Department of Zoology, Andhra University, Waltair, India)

INTRODUCTION

THERE is available a vast amount of literature on the long range hydrographical and biological conditions from various regions in the world. However, regular studies on short-term periodic variations in the hydrographical conditions of the sea are few. Leipper (1955) has discussed sea temperature variations associated with tidal currents in stratified shallow waters over an irregular bottom on the coast of Southern California. Skerman (1958) has given an account of the diurnal and seasonal variations in sea water surface temperatures within the New Zealand Harbours. Ealey and Chittelborough (1958) have described the diurnal variations of the temperature of the air and water, wind force, salinity, oxygen and plankton at Heard Island, Australia.

La Fond and Moore (1960) discussed sea temperature variations during a diurnal cycle off the coasts of Andhra and California. Perhaps, the only intensive account for the Indian waters comes from the contributions of Sewell (1925-'38) who made two-hourly observations on the salinity, specific gravity, temperature and wind force in the Bay of Bengal. Rangarajan (1958) has given an account of the fluctuations in the hydrobiological conditions through a diurnal cycle in the Vellar Estuary. In the present paper, periodic variations in the solar radiation, wind velocity, temperature of the air and water, tide, turbidity, salinity, dissolved oxygen, silicates, phosphates and phytoplankton at two stations on the coast of Waltair are described and discussed.

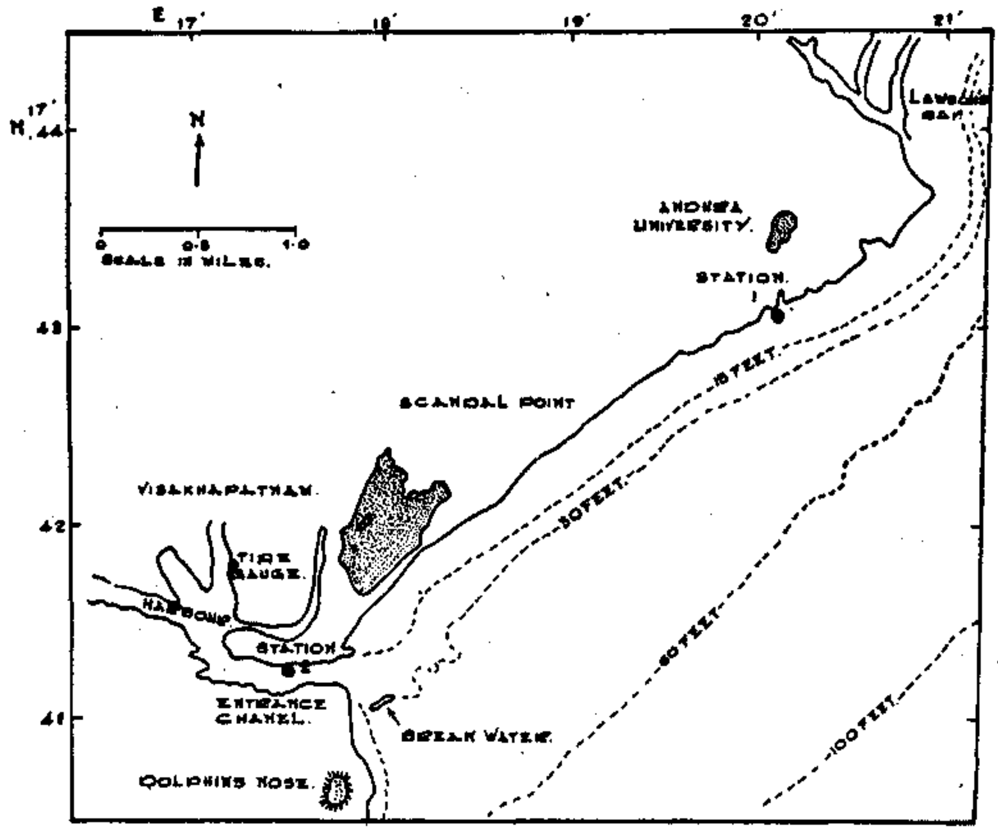
PHYSIOGRAPHY OF THE AREA

Surrounded by hilly ranges of the Eastern ghats, Waltair is situated at 17°-44′ and 88°-23′. The coast is rocky interspersed with wide stretches of sand. The average annual rainfall for Waltair is 34.27 inches. The total rainfall at Waltair during the period under review from October 1958 to May 1959 was 23.02 inches. There are no large rivers opening into the sea in the vicinity of Waltair. Influx of local drainage into the sea is poor.

The tides on this coast are regular semi-diurnal, the amplitude at the highest springs being 5′-9″ and at the lowest neaps 1′-4″, during the period of investigation,

Material and Methods

Two hydrographical stations (Chart), one at Palm Beach and the other at the entrance channel of the Visakhapatnam harbour, were fixed. At Station I the depth of the water was 2-3′ and at the channel (Station II) 15′. Diurnal or semi-diurnal studies were carried out approximately once in ten days during the period October 1958 to May 1959. Every time data on wind force, solar radiation, temperature of the air and water were obtained at two-hourly intervals through a tidal cycle. At the same time surface water samples were collected in glass stoppered pyrex bottles of 250 ml. and 125 ml. capacity. These samples were later analysed for turbidity, salinity phosphates and dissolved oxygen. For the estimation of silicate, water was collected separately in a 250 ml. polythene bottle.



Chart

The samples were fixed almost immediately after collection and stored in the dark. Bottles containing sea water for phosphate analysis were stored in a refrigerator.

Water samples for phytoplankton were collected in wide mouthed 300 ml. pyrex bottles and were immediately fixed with 5% formalin. At the time of estimation, 100 ml. of the sample were centrifuged at 2000 revolutions per minute for ten minutes and concentrated to 5 ml. The concentrate was counted in a Sedgwick-Rafter cell and the plankton was reported as numbers per liter.

A 4-cup anemometer was used for recording the velocity of the wind. A Days light photometer (Lux Meter) was used to measure solar radiation. Tidal data wa- obtained from the tide guage records kept by the Visakhapatnam port. Temperatures of the air and surface water were recorded by a sensitive centigrade thermometer. Turbidity was estimated by Hellige Turbidimeter, salinity by Knudsen's method, dissolved oxygen by Winkler's method, inorganic phosphate by Atkins-Deniges method as modified by Robinson and Thompson (1948) and silicate by the method of Robinson (1948).

Hydrobiological Conditions During a Diurnal Cycle

The data presented here deals with the diurnal observations carried out at station I on 24/25 February 1959. The details of the observations are given in Table I and Figs. 1-A & 1-B.

Table 1

Data relating to the Diurnal Cycle at Station 1 on 24/25th Feb. 1959

Time	Tide	Solar radiation	Wind force	Air temp.	Water temp.	Turbidity Sio*	Salinity	Oxygen	Phosphate	Silicate	Plankton
Hrs.	Feet	Lux units	M.P.H.	Oc	Oc	P.p.m.	°/₀₀	ml/1	μgat/1	μgat/1	Nos/1
1900	3.2	—	14	27.1	26.8	8.1	34.31	4.44	1.67	8.75	120
2100	4.9	—	8	26.7	25.8	10.9	34.67	4.34	1.72	8.75	410
2300	4.0	—	8	26.5	25.8	9.1	34.04	4.03	1.25	8.0	790
0100	1.4	—	6	25.0	25.5	14.0	34.22	3.94	1.25	—	540
0300	-0.6	—	6	24.5	25.3	11.5	34.31	4.27	1.25	10.0	910
0500	0.8	—	4	23.7	25.0	14.0	34.31	4.27	1.37	12.0	500
0700	2.4	12000	4	24.8	25.2	12.1	34.13	4.37	1.5	—	190
0900	4.3	18000	4	28.8	26.0	22.5	34.58	4.0	2.25	13.0	210
1100	3.9	80000	10	27.8	26.8	28.0	34.13	3.83	1,72	13.0	140
1300	1.6	80000	10	27.8	28.0	15.0	34.13	3.83	2.0	15.7	130
1500	-0.3	58000	12	27.8	28.2	21.5	34.13	3.92	1.67	17.0	1250
1700	0.0	—	10	27.7	27.2	22.5	34.13	3.89	1.37	—	720
1900	2.3	—	10	27.0	27.0	22.5	34.49	3.72	1.37	15.7	780

Tides and Tidal range. The observations covered two high and two low tides, each with a duration of 6 hours. The first high water was at 2100 hours and the second one at 0900 hrs. The first and second low waters were recorded at 0300 hrs. and 1500 hrs. respectively. The range between the first high and low waters was 5'-5" and in the second 4'6", thus showing a higher range in the night.

Air Temperature. The air temperature during the 24 hours period showed a range of 5.1°C. There was a gradual fall in the temperature from 1900 to 0500 hours. It showed a rapid increase after 0500 and reached the maximum at 1900 hours. Thereafter the temperature declined steadily through the evening.

Surface Water Temperature. There was a range of 3.2°C between the maximum and minimum temperatures recorded at 1500 and 0500 hrs. respectively. There was a general agreement between the trends of the air and the water temperatures throughout the diurnal cycle. They showed a gradual decrease during the night and increase during the day.

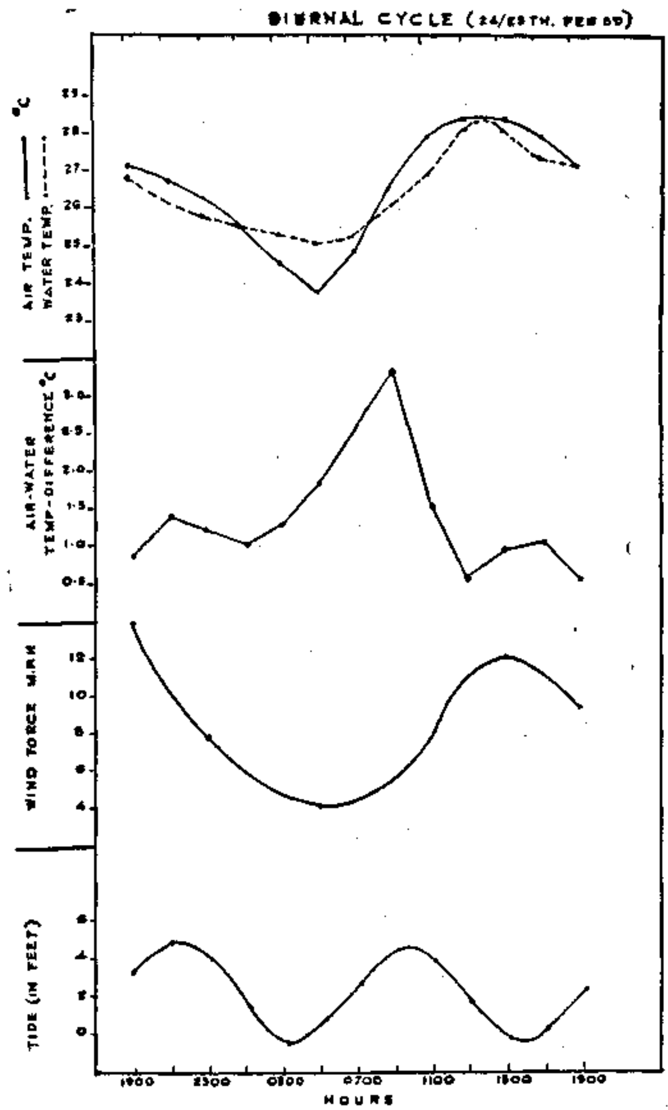


Fig. 1-A

Wind Force. The wind force exhibited a double oscillation during the 24 hour period. Highest wind velocity of 14 m.p.h. was recorded at 1900 hrs. and the lowest of 4 m.p.h. at 0300 hrs. Throughout the night, wind velocity was steady and low but it showed a steady rise through the morning hours.

Wind Force and Air and Water Temperature. (Fig. IA). Direct relationship was found between the wind force, air and water temperatures. For example, at 2100 hrs. when the wind velocity was at its highest, the temperature of air and water were also highest. In the succeeding hours there was a gradual fall in all the three components when all of them reached their minimum value at 0500 hrs. Thereafter they showed a gradual rise.

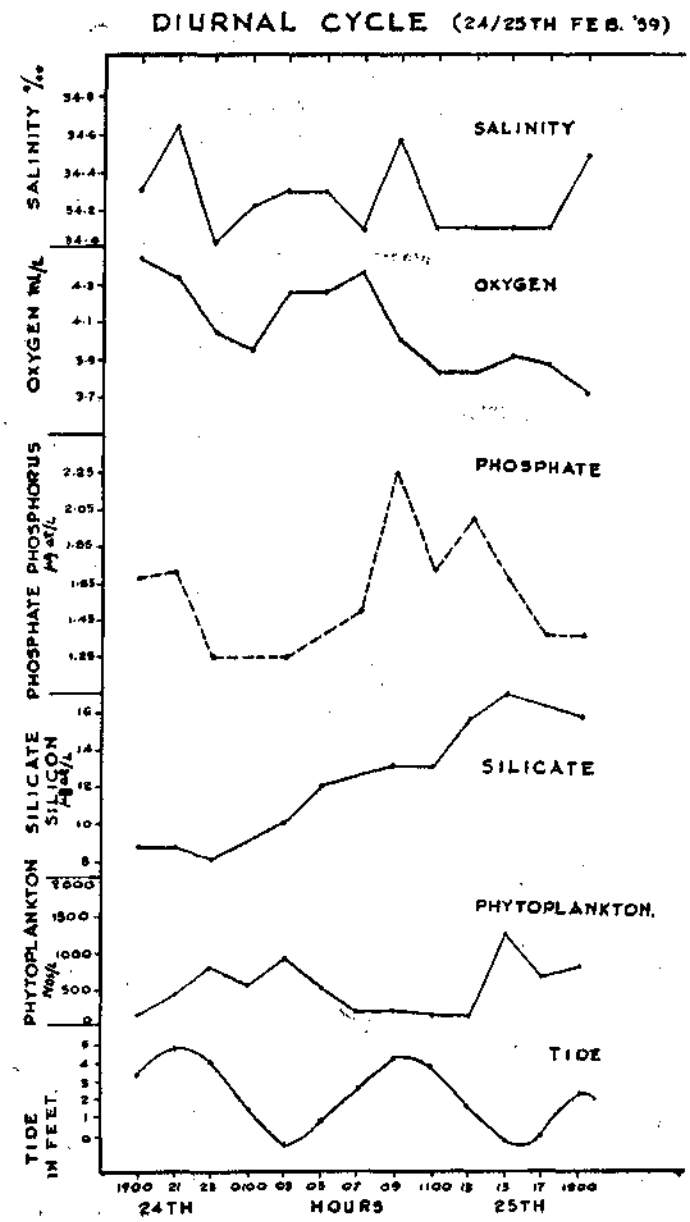


Fig. 1-B

A comparison of the fluctuations of wind velocity with that of the temperature difference between air and water revealed inverse relationship between the two.

Solar Radiation. The intensity of the solar radiation showed a single oscillation. There was a rise in the intensity from 0900 hrs. till 1300 hrs. after which it declined.

Salinity (Fig. 1B). The amplitude in the variation of salinity in a 24 hour period was low (0.63°/₀₀). At high tide the salinity was high and at low tide it was low.

Dissolved Oxygen. The concentration of dissolved oxygen in the surface water varied between a maximum of 4.44 ml/L. and a minimum of 3.72 ml/L. thus showing a diurnal range of 0.72 ml/L. The general trend of variation in oxygen concentration during a diurnal cycle was related to the ebb and flow of the tide.

Inorganic Phosphate. There was wide fluctuation in the concentration of inorganic phosphate in a diurnal cycle. A maximum of 2.25 μg. at/L. was recorded at 0900 hrs. and a minimum of 1.25 μg. at/L. between 2300 hrs. and 0300 hrs : a range 1.0 μg. at/L. Oscillation in the phosphate content throughout the diurnal cycle closely followed the tide. The values were high at high tide and low at low tide.

Silicates. The concentration of silicates in the surface water ranged from 17.0 μg. at/L. recorded at 1500 hrs. to a minimum of 8.0 μg. at/L. found at 2300 hrs. In general, during the night the values were lower than during the day.

Turbidity. The turbidity of the water showed a great variation between day and night. The maximum of 28.0 SiO_2 Parts per million was recorded at 1100 hrs., while the minimum of 8.1 SiO_2 P.P.M. was observed at 1900 hrs., thus showing greater values during the day time.

Phytoplankton. The fluctuation in the numbers of the phytoplankton was marked during a 24 hour period. The range was as much as 1130 organisms per litre (Table I). The numbers increased with the rising tide and decreased as the tide fell between 2300 hrs. and 0100 hrs. But surprisingly, at the peak of low tide there was a sudden increase in numbers which was the maximum for the night. Again, between 0900 and 1300 hrs., with the falling tide there was a fall in the numbers of plankton but at the peak of the low tide at 1500 hrs., there was an abrupt rise to the highest number for the day.

MONTHLY MEAN AND DAILY AVERAGE RANGES OF THE HYDROBIOLOGICAL CONDITIONS

Before describing the monthly mean and average daily ranges of the hydrobiological conditions, it is necessary to point out here that the present data covers a period of eight months, from October 1958 to May 1959. It corresponds with the general survey season of Sewell (1928-'32) in the Bay of Bengal for which data is available for comparison. Besides, the offshore hydrobiological data, processed for this coast by Ganapati and Murti (1954), Ganapati and Rama Sarma (1958), covers almost the same period. This is because June to September period happens to be cyclonic on this coast and regular collections are not possible. Further this eight-month period represents the period of the year in which important changes are known to take place in the marine meteorological and hydrobiological conditions.

Air-Temperature. The monthly average temperature of the air showed two maxima, one in November and other in May. The minimum temperature was recorded in December. There was a range of 3.9°C in the temperature of the air during the period of the study. The average daily range of temperature varied from month to month. It showed a maximum of 5.7°C in January and minimum of 1.5°C in May. A comparison of the average daily range of the air temperature with its monthly mean values indicated that whenever there was high air temperature the range was at its minimum. Thus there seems to be an inverse relationship between the two.

Surface Water Temperature. (Table 6, Fig. 2A). The variation in the monthly mean surface water temperature was from a maximum of 29.4°C in October to a minimum of 25.8°C. recorded in December, the range being 3.6°C. There was a clear double oscillation in the water temperature just as in the air temperature. The water reached its first maximum temperature a month earlier (October) than that of the air, but the second maximum temperatures of both air and water occurred in the month of May.

The range of temperature of the water observed in a day was almost equal in magnitude to the range in the monthly mean temperature. Average daily range of surface water temperature varied from month to month. It showed a maximum range of 2.8°C in May and a minimum range of 1.4°C in January.

Relation between Air and Water Temperature. (Table 6). Surface water temperature was higher than air temperature during October, January and February and in the remaining months of observation the reverse was the case (Fig. 2B). The difference between the air and water temperatures was always high early in the morning and the difference nearly vanished towards the afternoon. The daily range of air temperature was at its maximum in January when that of the water was at its minimum and it was vice versa in May (Fig. 2A).

Wind Velocity. (Table 6, Fig. 2A). There was a double oscillation in the monthly mean velocity of the wind. There were two maxima, of which one was in November and the other in May. The wind velocity declined from November till January when it reached its minimum and from February onwards there was a gradual rise till May.

The average daily range in the wind velocity closely followed the trend of the monthly mean values.

Relation between Wind Force and Air and Water Temperatures. The monthly means of air and water temperatures closely followed the wind force, showing a rise and fall together in the various months excepting in January. This kind of relationship also existed between wind force, air and water temperatures during the course of a diurnal or a Semi-diurnal cycle.

Wind Force and Temperature difference between Air and Water. Wind force was very low early in the morning between 0600 and 0700 hrs. throughout the period of

TABLE 6

Monthly mean values and average daily ranges of the Physical and Hydrographical conditions during October 1958—May 1959

	Solar radiation 'Lux'	Wind force M.P.H.	Turbidity SiO_2 p.p.m.	Air temp. °C	Water temp. °C	Air-Water Temp. diff. 0c	S ‰	O_2 ml/1	PO_4 ug at./l.	Si ug at./l.	Months
Monthly Mean.	62200	—	3.40	28.67	29.48	0.81	25.75	4.73	0.51	—	Oct.
Daily range.	50660	—	2.47	3.34	2.20	—	0.96	0.33	0.15	—	
Monthly Mean.	55260	10.1	4.62	29.28	28.12	1.16	23.03	4.21	0.44	32.84	Nov.
Daily range.	39660	9.0	1.55	3.25	1.5	—	1.52	0.37	0.65	6.15	
Monthly Mean.	42540	6.07	3.13	25.87	25.85	0.02	26.08	4.61	0.60	27.25	Dec.
Daily range.	60500	6.25	2.00	5.06	1.65	—	0.44	0.36	0.19	10.12	
Monthly Mean.	50620	4.61	6.59	26.01	26.88	0.87	29.90	4.67	0.72	6.97	Jan.
Daily range.	74500	6.00	5.86	5.76	1.4	—	0.51	0.44	0.16	2.38	
Monthly Mean.	54320	8.08	11.39	26.77	26.00	0.13	32.88	3.93	0.74	11.27	
Daily range.	66000	8.3	9.96	4.46	2.36	—	0.41	0.66	0.39	7.16	Feb.
Monthly Mean.	54940	8.55	11.23	28.34	27.67	0.67	34.03	4.31	1.19	9.63	
Daily range.	39340	9.00	12.25	4.25	2.7	—	0.46	0.73	0.67	6.99	Mar.
Monthly Mean.	52700	8.6	16.53	28.77	27.86	0.91	34.29	4.36	0.61	10.15	April
Daily range.	49500	7.31	12.23	3.7	1.9	—	0.49	0.73	0.37	7.10	
Monthly Mean.	69360	9.55	10.99	29.86	29.26	0.60	34.29	4.53	0.23	9.79	May
Daily range.	59200	8.0	10.95	1.5	2.8	—	0.41	0.32	0.08	3.75	

investigation except during the second fortnight of February when the wind force during these hours was very high (Table 2). When wind velocity was low, the temperature difference between air and water remained high and this difference was found to decrease with increasing wind force. Generally at this early hour, the water temperature was higher than the air temperature.

Salinity. (Table 6, Fig. 2B). There was a variation in the monthly mean salinity from 34.29‰ in April and May to 23.03‰ in November, thus showing a range of 11.26‰. Salinity values exhibited a single seasonal oscillation with a minimum in November followed by a gradual rise to a maximum in May.

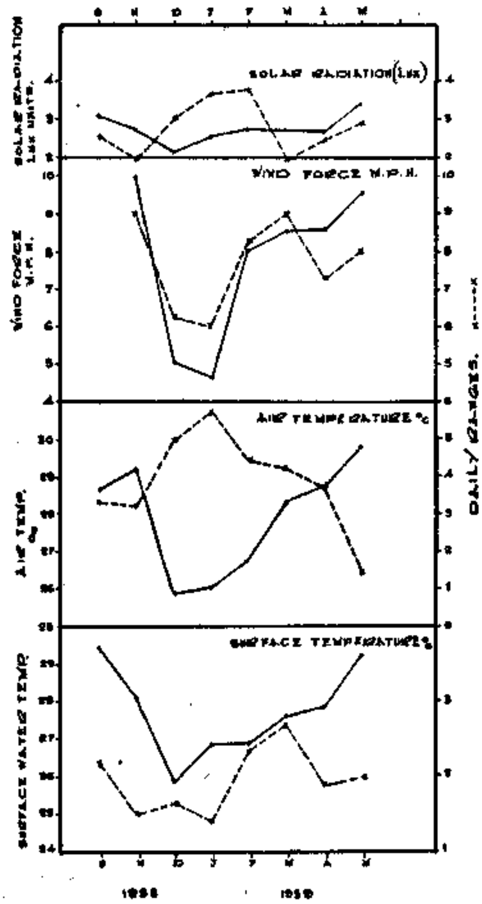


Fig. 2-A

The average daily range in salinity fluctuated in a haphazard manner with a maximum of 1.52‰ in November and a minimum of 0.41°/₀₀ in February and May. There was a clear correlation between monthly mean salinity and daily ranges in the various months. During October and November when minimum monthly salinity occurred, average daily ranges were high and from December to May when salinity was high daily range was found to be low.

Dissolved Oxygen. From the values presented in Table 6, it is seen that dissolved oxygen was found to vary from 4.78 ml/1 in October to 3.39 ml/L in February. The range was 0.8 ml/L. A comparison of this range with the range of

0.72 ml/L found in a single day indicates that the variation of the dissolved oxygen content through several months is of the same magnitude as that taking place in a day.

TABLE 2

Wind Force : Air and Water Temperature Difference

Time Hrs.	Temp. Difference Oc	Wind Force M.P.H.	Time Hrs.	Temp. Difference Oc	Wind Force M.P.H.
	14-11-58			5-2-59	
0800	0.7	4	0630	3.0	2
1000	0.2	8	0830	0.3	4
1200	1.2	12	1030	0.3	6
1400	0.9	12	1230	0.4	8
1600	0.7	14	1430	0.4	8
1800	0.0	14	1630	0.6	10
2000	0.0	14	1830	1.1	10
	30-12-58			14-3-59	
0730	4.0	0	0630	2.0	4
0930	0.4	8	0830	1.9	8
1130	0.5	8	1030	0.7	12
1330	0.5	6	1245	0.4	12
1530	0.4	8	1430	1.2	10
1730	0.3	4	1630	0.4	12
1930	1.1	0	1830	0.5	12
	21-1-59			6-5-59	
0700	3.4	0	0700	1.8	4
0900	0.3	4	0900	1.8	8
1100	0.8	6	1100	0.6	8
1300	0.0	6	1300	0.0	12
1500	0.8	4	1700	0.3	14
1700	1.3	8	1900	0.1	14
1900	1.4	8			

There was a direct relationship between the monthly mean values of oxygen and temperature of the surface water throughout the period of study except in February when it was inverse.

A direct relationship was found between the oxygen content of the water and the prevailing tide (Table 4). The values were high at high tide and low at low tide. Average daily range of the oxygen content varied from 0.32 ml/L in May to 0.73 ml/L in March and April. There was an inverse relation between the mean monthly values and the average daily range of oxygen content of the surface water.

Silicates. Monthly mean values showed a wide range between a maximum of 32.84 μg at/L in November to a minimum of 6.97 μg. at/L in January.

The amplitude in the average daily range was from a maximum of 10.12 μg. at/L in December to a minimum of 2.38 μg. at/L in January. The daily range and the monthly mean values followed each other closely from December onwards.

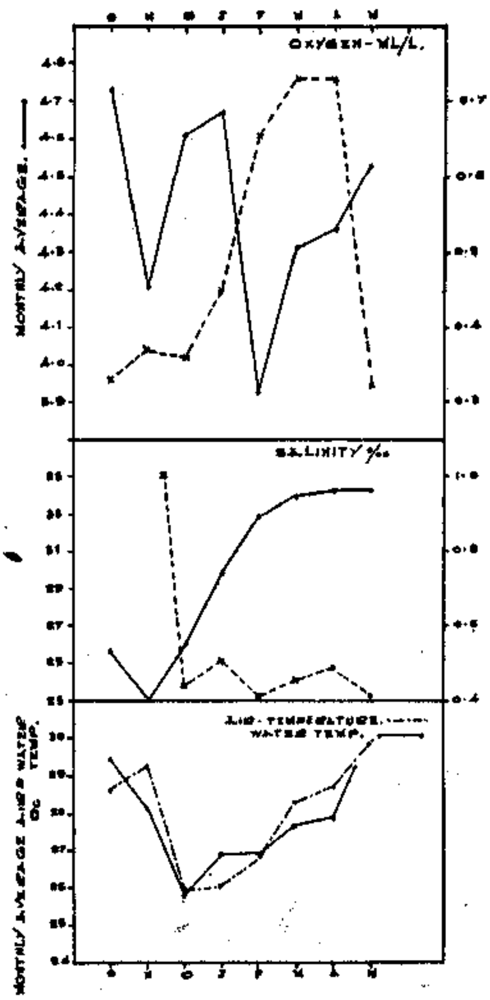


Fig. 2-B

Phosphate. There was considerable variation in the mean monthly inorganic phosphate values. The maximum phosphate of 1.193 μg. at/L was found in March and the minimum of 0.23 μg. at/L in May. The range in the variation of phosphate in the period of study was 0.963 μg. at/L.

The average daily range fluctuated between a maximum of 0.675 μg. at/L in March and a minimum of 0.08 μg. at/L recorded in May.

Discussion

For a proper understanding of the significance of the results obtained in the present investigations, it would be helpful to consider the location of the two stations at which the data was collected. At Station I situated on the open shore and subject to heavy wave action, the depth was only 2 to 3′. At Station 2 located in the entrance channel of the Visakhapatnam harbour, the waters were relatively free from breaking action of the waves and had a depth of nearly 15′.

Air Temperature. The daily range of air temperature varied from month to month on this coast. It showed a double oscillation and agreed with Eliot's (1902) observation for Madras where a similar double oscillation was found. But Sewell (1927) noticed a single oscillation for land areas such as Bombay (refer Table below) and double oscillation for the open sea. For comparison, the daily range of air temperature at different places is given below (Sewell 1927).

	Bombay	Bay of Bengal	Bay Islands	Nankauri Harbour	Open Waters of Indian seas	Waltair
October	10.3	7.8	5.4	6.2	1.77	3.34
November	13.7	10.5	5.3	5.6	1.69	3.25
December	14.2	12.4	5.2	5.7	1.73	5.06
January	14.4	12.7	6.0	4.8	1.82	5.76
February	14.7	13.2	7.1	5.4	1.90	4.46
March	14.3	12.7	7.9	5.7	1.95	4.25
April	12.8	11.3	7.5	6.1	1.90	3.70
May	12.8	9.3	5.7	6.0	1.75	1.50
June	8.7	6.9	4.5	5.8	1.67	—
July	6.4	5.7	4.4	5.8	1.76	—
August	6.3	5.4	4.4	5.8	1.58	—
September	7.8	5.8	4.6	6.3	1.56	—

Surface Water Temperature. Analysis of the data of surface water temperature showed a single oscillation in a semidiurnal and diurnal cycles and also in the monthly averages (Table 7). Sewell (1927) recorded in the Nankauri Harbour a double oscillation both during a diurnal period and in the monthly averages. In the Bay of Bengal (Table below) the relation between the monthly average surface temperatures and the maximum daily temperature range of the water was found to be inverse (Sewell 1927) but on this coast a direct relationship was noticed. The inverse relationship between the monthly mean temperature and the daily range obtained by Sewell in the case of the sea water was seen here in regard to air.

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May
Bay of Bengal (water temperature in °C.)								
Monthly average	27.40	27.36	26.09	23.71	27.51	27.71	28.86	27.50
Daily range	4.50	5.00	6.45	—	5.50	4.49	3.60	—
Waltair (water temperature in °C.)								
Monthly average	29.48	28.12	25.85	26.88	26.90	27.67	27.86	29.26
Daily range	2.20	1.50	1.65	1.40	2.36	2.70	1.90	2.80
Air temperature (in °C.)								
Monthly average	28.67	29.28	25.87	26.01	26.77	28.34	28.77	29.86
Daily range	3.34	3.25	5.06	5.76	4.46	4.25	3.70	1.50

TABLE 7

Comparative account of yearly, diurnal and semidiurnal fluctuations of the hydrobiological conditions

	Yearly	Diurnal	Semidiurnal
Air Temp. 0C Range	Double oscillation (2 maxima, 2 minima) 3.99	Single oscillation (1 max, 1 min) 5.1	Single oscillation 4 - 5.5
Water tempt. 0C Range.	Single oscillation 3.65	Single 3.2	Single 1 - 3.2
Wind Force Range	Double oscillation 5.49	Double 10	Double or single 8
Air temp. Water temp. Wind force.	Direct relation	Direct	Direct
Air, water temp. difference.	Triple oscillation	Triple	Double or single
Air, water temp. difference. Wind force	Irregular trend somewhat direct	Inverse relation	Inverse relation
Salinity % Range	Double oscillation 11.26	Double 0.63 Direct relation with tide	Double or single 0.36 - 0.57 Both direct and inverse relation
Oxygen ml/1 Range O_2-temp. O_2-tide	Double oscillation 0.83 Direct relation —	Double 0.61 Inverse Direct	Single 0.3 - 0.6 Direct Direct
Phosphate μgat/1 Range Po4-temp. Po4-tide	 0.96 Inverse relation —	 1.0 Inverse Direct relation	 0.12 Inverse and also direct Direct
Silicate, μgat/1 Range	25.87	9	4 - 9
Phytoplankton	—	Inverse relation with tide.	Inverse relation

In the present investigation it was found that the water temperatures were higher than air temperature in the months of October, January and February. Further, it was found that during the entire period of investigation the early morning water temperature was always higher than air and the reverse was true during the rest of the hours.

Air-Water Temperatures and Wind Force. These three factors were directly interrelated in their monthly mean values as well as in the hourly variations. The monthly mean values of these factors recorded a fall from November to December and showed a distinct rise from February to May. In the individual cycles too, early in the morning, when the wind force was very low, both temperatures were low and with an increase in the wind velocity during the day the temperatures of air and water also rose.

Over the open waters of the Laccadive sea a rise of air temperature coincided with a fall in wind force and vice versa, except during the early hours of the afternoon when the wind effect was some what masked by the influence of the solar radiation (Sewell 1929). But in the Andaman sea, it could be seen from the Table below that there was a direct relation between these factors.

Hours	0040	0080	1200	1600	2000	0000
Andaman Sea, Feb. 1922 : (*After Sewell* 1929, p. 236)						
Sea temperature °C.	27.50	28.00	29.00	28.60	28.10	27.70
Air temperature °C.	26.11	27.33	28.00	27.56	26.83	26.67
Air sea temperature difference °C.	1.39	0.67	1.00	1.04	1.27	1.03
Wind force	1.25	2.00	2.00	1.50	1.25	1.00

Hours	0630	0830	1030	1230	1500	1630	1830
Waltair coast May 1959 :							
Sea temperature °C.	27.20	28.00	28.20	29.90	30.30	30.00	29.2
Air temperature °C.	29.30	30.00	29.50	30.30	30.30	30.00	29.0
Air and sea temperature difference °C	2.10	2.00	0.30	0.40	0.00	0.00	0.2
Wind force (m.p.h.)	4	8	10	12	10	10	10

A distinct relationship was seen between the wind force and temperature difference throughout the period of investigation. The relationship was inverse from December to January and April to May and in the remaining months a rise in the wind force was followed by a rise in the temperature difference. Sewell obtained from October to January a direct relationship and during the subsequent months an inverse relationship between these factors.

It is interesting to note here that the diurnal range of 5.1°C. in air temperature and 3.2°C. in the surface water temperature are equivalent in magnitude to the range between the monthly means from October to May. A similar observation was made by Skerman (1958) for the surface waters of the New Zealand Harbours. He observed that the diurnal range of 4°C. was equal to the range between the monthly means for August and November i.e. (mid winter and late spring).

Surface water temperatures varied with the ebb and flow of the tide. During low tide the surface temperature was found to be low in half the number of tidal cycles worked out on this coast and high in the remaining half (Table 3). This meant that the relationship between the tide and water temperature could be either direct or indirect. Skerman (1958) has pointed out ' that the times corresponding to the rise, peak and fall of the water temperature do not appear to be dependent on the state of the tide '. It may be pointed out that the effects of tide, solar radiation and wind force on the fluctuations of water temperature at these littoral stations are however not so obvious.

TABLE 3

Tide : Temperature : Salinity

Date	Temperature °C		Salinity ‰	
	High tide	Low tide	High tide	Low tide
6-10-58	30.09	29.69	27.18	27.68
25-10-58	29.8	30.4	24.47	23.68
*4-11-58	27.8	27.0	19.20	17.57
14-11-58	28.6	28.3	25.37	25.01
14-12-58	25.85	26.2	24.92	25.10
*17-12-58	27.0	25.5	25.10	24.65
25-12-58	25.6	27.0	27.23	27.23
30-12-58	26.0	25.30	27.32	27.05
9-1-59	25.9	27.0	27.09	27.05
21-1-59	26.8	27.84	30.77	31.31
*28-1-59	26.8	27.4	31.67	31.31
5-2-59	27.1	27.6	30.86	31.40
15-2-59	28.5	26.5	32.9	32.38
24-2-59	25.8	25.3	34.67	34.31
*25-2-59	26.8	27.2	34.13	34.13
14-3-59	26.4	28.2	33.49	34.05
*25-3-59	27.0	28.1	33.96	34.14
13-4-59	28.7	29.2	34.31	33.96
*19-4-59	26.8	28.8	33.08	34.21
24-4-59	27.0	26.7	34.58	34.31
25-4-59	27.3	28.2	34.49	34.13
6-5-59	27.8	30.3	34.13	34.31

* Observations at the Entrance Channel.

A direct relationship between the tide and salinity was found by Sewell (1929), Ealey and Chittelborough (1958) and Rangarajan (1958). The local observations revealed two kinds of relationship between the tide and salinity. In some tidal cycles high tide was accompanied by higher salinities and in others low tide brought in higher salinities (Table 3). The former relationship could be explained by assuming that the high tide waves brought in waters of higher salinity from off-shore areas. Increased temperature of water and higher rate of evaporation at low tides might explain the later conditions obtained, during certain periods on this coast.

Wind force is another factor that is known to cause daily fluctuations in the salinity. An increase in the wind force could cause, (1) an increase in the rapidity of the surface current, (2) an increase in the height of the waves thereby increasing the amount of admixture between the upper and lower levels of water, (3) and an increase in the rate of evaporation. All these factors can bring about changes in the salinity of the surface waters.

A triple oscillation was observed in the salinity during the 24 hour period on this coast. The two peaks in the salinity corresponded to the double oscillation of the wind velocity. But a time lag of two hours was found between the maximum wind force and maximum salinity. The third peak, since it was not accompanied by a maximum in the wind force in the preceding two or four hours and since it occurred at the epoch of the peak of the high tide, it was perhaps attributable to the effect of the flooding.

In this connection the present twenty-four hour observations may be compared with the offshore data available for the Station 24, Cruise 1 (dated 29/30 October 1952) off this coast. This station was located nearly twenty-five miles from the shore and the fluctuation of the different factors are given in Table 8.

TABLE 8

Data relating to a Diurnal cycle at Station 24 off the Waltair coast on the 29/30 October 1952

Time Hrs. 29/30	Surface water Temp. 0C.	Air temp. 0C.	Wind force (Beaufort scale)	Salinity ‰
0000	27.78	27.78	1	—
0156	27.67	27.22	0	28.48
0315	27.39	27.22	1	28.22
0404	27.56	27.17	1	—
0610	27.89	27.22	1	—
0745	28.11	27.89	1	29.51
1000	28.28	29.44	1	—
1200	28.39	29.44	1	30.28
1405	28.56	28.22	2	—
1600	28.56	28.89	1	29.85
1800	28.59	27.78	1	29.31
2005	28.22	28.22	1	—
2200	27.78	27.78	1	29.58
0000	27.94	27.94	1	—
Range.	1.17°	2.28°		2.06°/oo

From a study of the Table 8, it would seem that the ranges in the wind force, air and water temperature are lower than the ranges obtained in the inshore environment. But salinity shows a much wider range of nearly 2.06‰ during a diurnal cycle (29/30 October 1952).

Sewell (1929) found considerable ranges in the diurnal variation of salinity for all the months of the year in the surface waters of the Bay of Bengal and the Andaman sea and concluded (*loc. cit.* p. 343) ' that there is each day a double oscillation in the strength of the wind in these Indian regions and that twice a day an increase in the wind force causes a thinning of the surface layer of the ocean to an extent that

TABLE 5

Surface water temperature : Dissolved Oxygen

Date	Temperature °C	Oxygen ml/l
6-10-58	30.2 26.58	5.14 4.67
25-10-58	30.4 29.5	4.63 4.52
*4-11-58	28.7 27.0	4.33 3.83
14-11-58	28.6 27.3	4.41 4.33
14-12-58	26.7 24.6	4.66 4.60
*17-12-58	27.0 25.5	4.24 3.94
5-12-58	26.8 24.8	5.09 5.09
*30-12-58	26.2 25.2	5.04 4.88
9-1-59	27.1 25.2	4.98 4.99
21-1-59	27.8 26.4	4.74 4.77
*28-1-59	27.4 26.5	5.04 4.08
5-2-59	27.9 26.0	4.49 4.39
*15-2-59	28.5 26.5	3.28 3.18
14-3-59	29.5 26.0	4.44 4.61
*25-3-59	28.9 27.0	4.77 3.53
13-4-59	29.8 27.7	4.55 4.56
*19-4-59	28.8 26.8	3.64 3.85
24/25-4-59	28.2 26.5	4.55 4.61
6-5-59	30.3 27.8	4.65 4.79
12-5-59	30.3 27.2	4.17 4.55

* Observations at the Entrance Channel.

causes an upwelling of water from below either actually to the surface or to such a height that this deeper water becomes mixed with the surface layer ; and that this movement of the water masses produces corresponding effects both on the temperature relationship of the sea and the air and on the surface-salinity and the corresponding relationships of the surface and deeper strata of the ocean.'

Some such cause should be responsible for the difference and range in the salinity values recorded at station 24, and the same might be reflected on a smaller scale in the inshore environment under discussion.

Dissolved Oxygen. Three factors, namely respiration, photosynthesis of phytoplankton and algae and the temperature of the surface waters are known to influence the distribution of oxygen in the littoral regions of the sea. Intense photosynthetic activity would bring about an increase in the oxygen content of the water. An inverse relationship between oxygen and temperature has been observed by Redfield (1948) Dakin and Colefax (1935) Ramamurthy (1953) and Kasturirangan (1957).

In the present observations, the relation between dissolved oxygen and temperature was rather peculiar. In the monthly mean values (Table 6) as well as in the values obtained during a diurnal (Table 1) and several semidiurnal cycles (Table 5) oxygen showed a direct relationship with the temperature of surface waters. Similar relationship in the monthly mean values had already been observed in the near shore areas off Waltair by Ganapati and Ramasarma (1958), and in a diurnal cycle by Rangarajan (1958) in Vellar estuary.

Another factor that appears to be important in the distribution of the oxygen is the tide. The oxygen content of the water was high at high tide and low at low

TABLE 4

Tide : Oxygen

Date	High tide Feet	Oxygen ml/l	Low tide Feet	Oxygen ml/l	Tide Range Feet	Oxygen Range ml/l
6-10-58	5-0	4.98	3-4	4.74	1-6	0.24
*4-11-58	6-2	4.33	4-3	3.83	1-9	0.5
14-12-58	4-6	4.68	1-5	4.60	3-1	0.08
*17-12-58	4-0	4.24	1-7	3.94	2-3	0.00
25-12-58	4-5	4.98	0-5	4.93	4-0	0.05
*30-12-58	4-0	4.94	0-8	4.88	3-2	0.06
9-1-59	4-2	5.05	0-1	4.88	4-3	0.17
*28 -1-59	4-2	4.38	0-5	4.35	3-7	0.03
5-2-59	4-2	4.49	0-3	4.40	3-9	0.09
*15-2-59	2-9	3.28	0-6	3.18	2-3	0.10
*24/25-2-59	4-9	4.34	0-6	4.27	5-5	0.07
14-3-59	3-8	4.65	0-3	4.44	3-5	0.21
13-4-59	3-7	4.64	0-7	4.55	3-0	0.09
*19-4-59	3-6	3.85	0-5	3.64	3-1	0.21
25-4-59	5-1	4.76	0-2	4.55	4-9	0.19
6-5-59	4-4	4.79	1-0	4.65	3-4	0.14

* Observations at the Entrance Channel.

tide, but the values did not closely follow hour by hour the tide. Ealey and Chittelborough (1958) found little variation in oxygen values with the tide. Rangarajan (1958) did not find any correlation between the oxygen content and the tide in the Vellar estuary. It is possible that greater turbulence created by the inflowing high tide is responsible for the increase in the oxygen content of water at high tide.

Inorganic Phosphate. It is interesting to note that the range in variation of phosphate concentration in a diurnal cycle was as much as 1.0 μg. at/L. (Table 7), and in the other semidiurnal cycles it was about 0.5 μg at /L. Throughout the period of study the monthly range in variation was 0.96 μg at/L.

In the present investigation, phosphate concentration was found to follow closely that of the tide. It was high at high tide and low at low tide. Increase of phosphates in the surface waters on this coast in the month of June had been attributed to the dredging operations conducted by the Visakhapatnam Harbour authorities (Ganapati and Subba Rao 1958). But this does not fully explain the repeated occurrence of high phosphates obtained at high tides during the various tidal cycles.

Silicates. The seasonal silicate values showed a range between the maximum of 32.84 μg at/L. recorded in November and the minimum of 6.97 μg at/L. found in January.

In a number of cycles silicates showed an inverse relation with the tide, but on the whole, the silicate values presented an irregular trend.

Phytoplankton. In a diurnal cycle maximum numbers of phytoplankton were encountered at the epoch of maximum low tides and lower numbers at the epoch of maximum high tides. This is clear from the table below :

25-10-'58	Tide (in feet & inches)	6.6	5.5	3.4	3.5	4.9	6.6	6.9
	Nos. of Phytoplankton.	120	210	720	510	300	300	500
30-12-'58	,, ,,	2.1	3.9	4.0	2.6	1.0	0.8	2.4
		220	680	980	710	520	2430	1580
28-1-'59	,, ,,	2.2	4.2	4.2	2.4	0.5	0.7	2.7
		60	410	170	140	1290	520	170
5-2-'59	,, ,,	3.5	3.1	1.3	0.3	0.6	2.4	4.2
		410	400	370	310	900	700	500
6-5-'59	,, ,,	4.4	4.2	2.3	1.0	1.3	3.0	4.2
		750	450	440	1040	520	510	720

CONCLUSIONS

The present study has revealed that there are substantial variations in the hydrobiological conditions of the surface waters in short periods of time in the inshore areas of the sea.

In many instances as in the case of air, water temperatures, wind force and dissolved oxygen, the diurnal range was almost equivalent in magnitude to the annual ranges. This should be of great importance in the physiological activities of the organisms, because an animal might find the occurrence of a suitable temperature for some physiological activity such as spawning throughout the year in these waters. This also perhaps would explain the large number of broods in a year met with in the tropical marine communities. In contrast to this a boreal or an arctic organism will have to wait till the advent of the proper season for the occurrence of a particular temperature.

SUMMARY

Diurnal and semidiurnal variations of some physical, chemical and biological characteristics of the sea water were studied during October 1958 to May 1959 at two littoral stations situated on the Waltair coast (17°-44′ and 88°-23′). Wide fluctuations in the air and water temperatures, solar radiation, wind force, turbidity, phosphate, silicate and phytoplankton and narrow ranges in salinity and oxygen were met with. Air and water temperatures and wind force showed a direct relationship among themselves, while air and water temperature difference was inversely related with wind force. There was a direct relationship between the dissolved oxygen and surface temperature and tide. Quantitative distribution of phytoplankton showed maximum numbers at the peak of low tide and the minimum at the peak of high tide. The daily range in air temperature, water temperature, wind force and dissolved oxygen was almost equal in magnitude to the annual range of these factors on this tropical coast.

ACKNOWLEDGEMENTS

We take this opportunity to express our grateful thanks to Prof. P. N. Ganapati, Head of the Department of Zoology for providing excellent facilities and encouragement during the course of the work. We are also indebted to Prof. E. C. La Fond, and Dr. V. P. Subrahmanyam for kindly going through the manuscript and offering useful suggestions.

REFERENCES

DAKIN, W. J. AND COLEFAX, A. N. 1935. Observations on the seasonal changes in temperature, salinity, phosphates, nitrates, oxygen of the ocean waters on the continental shelf off New South Wales and relationship to the plankton production. *Proc. Linn. Soc. N.S.W.*, **60** : 303-314.

EALEY, E. H. M. AND CHITTLEBOROUGH, R. G. 1958. Plankton, Hydrology and Marine fouling at Heard Island. *Australian National Antarctic Research Expedition*, Interim Reports, No. 15.

GANAPATI, P. N. AND MURTY, V. S. R. 1954. Temperature and salinity variations in the waters off Visakhapatnam. *Andhra Univ. Mem. Oceanogr. Ser.* **49** : 125-142.

GANAPATI, P. N. AND RAMASARMA, D. V. 1958. Hydrography in relation to production of plankton off Waltair coast. *Ibid.*, **62**, (2) : 168-192.

GANAPATI, P. N. AND SUBBA RAO, D. V. 1958. Quantitative study of plankton off Lawson's Bay, Waltair. *Proc. Ind. Acad. Sci.*, **48** : 189-209.

———. 1958. Dredging and Phytoplankton production *Curr. Sci.*, **27** : 349-350.

KASTURI RANGAN, L. R. 1957. A study of the seasonal changes in the dissolved oxygen of the surface waters of the sea on the Malabar coast. *Ind. J. Fish.*, **4** : 134-149.

LA FOND, E. C. AND MOORE, A. T. 1960. Short period variations in sea water temperatures. *Indian J. Meteor. & Geophys.*, **11**(2) : 163-166.

LEIPPER, DALE F. 1955. Sea temperature variations associated with tidal currents in stratified shallow water over an irregular bottom. Reprint from Sears Foundation, *Jour. Mer. Res.* and contribution from Scripps Institution of Oceanography, New Series, No. 746.

RAMA MURTHY, S. 1953a. Seasonal changes in Hydrogen-ion concentration and dissolved oxygen content of the surface water of Madras coast. *J. Madras Univ.*, B. **23** : 52-61.

Rama Murthy, S. 1953b. Hydrobiological studies in the Madras coastal waters. *J. Madras Univ.* B. **23** : 148-164.

Rangarajan, K. 1958. Diurnal Tidal Cycle in the Vellar Estuary. *J. of Z. Society of India.* **10** : 54-67.

Robinson, R. J. and Thompson, T. G. 1948. The determination of phosphate in sea water. *J. Mar. Res.*, **7** : 33-39.

Robinson, R. J. 1948. The determination of silicate in sea water. *Ibid.*, **7** : 49-55.

Sewell, R. B. S. 1927. Maritime Meteorology in Indian seas. *Memoirs of the Royal Asiatic Society of Bengal*, **9** : 51-130.

———. 1929. Geographic and Oceanographic Research in Indian waters. *Ibid.*, **9** : 207-356.

Skerman, T. M. 1958. Seasonal variations in sea water surface temperatures within New Zealand Harbours. *New Zealand Journal of Geology and Geophysics*, **1** : 197-218.