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CONTENTS

I. INTRODUCTION

As mentioned in a previous publication (Seshappa, 1953 *a*) observations were started in January 1952, on the bottom muds of the West Hill Sea near Calicut (Malabar Coast) with a view to elucidating their role in the inshore phosphate cycle, this latter being known to be of great importance in determining the biological cycles and fishery productivity of any aquatic area. The studies consisted of routine examination and analyses of mud samples from two selected stations (4 metres and 19 metres) for temperature, pH, percentage of silt colloidal matter, moisture percentage and also the interstitial and adsorbed phosphate. Total phosphorus was also determined on some occasional samples. Bottom water samples were collected simultaneously with the mud samples from both the stations and studied for temperature, pH, chlorinity and dissolved inorganic phosphate. The work was continued upto March 1953; the results obtained form the subject matter of the present paper and show that the muds are of great importance as reservoirs of phosphate.

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We are thankful to Dr. N. K. Panikkar for suggesting this work and for valuable discussions both during the progress of the work and in the preparation of the same for publication.

II. Methods

Collection of samples.—The mud samples were collected by means of a grab sampler and were taken from the surface 4″ of the sea bottom. Water samples were taken by means of a Casella bottle.

Temperature.—The temperature of mud was taken by inserting a thermometer deep in the centre of the grab sample as soon as the sample was taken aboard, the sample being as little disturbed as possible while taking it out of the grab.

Silt suspension.—A known weight of the mud (wet weight) was taken and a silt suspension was prepared after passing the sample through a set of sieves of the mesh types described by Rochford (1951). The suspension was made up to one litre and used for analysis.

Moisture content.—A known wet weight of the mud sample was taken and dried to constant weight at 105° C. in an electric hot-air oven. Three sub-samples were analysed for moisture content in each sample. The moisture content is expressed as a percentage of wet weight.

Silt percentage.—This was estimated as follows: The silt suspension was prepared as mentioned above. 50 c.c. of the suspension was taken before the samples for phosphate determination were taken and 50 c.c. afterwards. The two were dried to constant weight at 105° C. and these values used along with the dry weight and wet weight of a known quantity of mud, gave the silt content of the mud samples.

The analytical methods followed in this investigation were the same as described by Rochford (1951). pH determinations were made by shaking a small quantity of the mud with 20 ml. of distilled water, filtering and using cresol red indicator with the filtrate. A BDH Lovibond comparator was used for arriving at the pH values.

No preservative was used with the samples. They were all collected early in the morning and analysis was started as soon as they reached the laboratory, usually by about 10 A.M.

Water samples were also analysed fresh for pH and phosphate content. The water layer immediately above the bottom where mud samples were taken, was the one sampled for this purpose:

III. RESULTS

Temperature.—Tables I and II show the mean monthly values of the mud and water temperatures for both the stations.

TABLE I

Monthly average values of the temperature of the bottom mud and of the overlying water, in degrees centigrade in Station I

(4 Metres)

Month		No. of samples examined	Surface water	Bottom water	Mud	Remarks
January	1952 ..	5	29·3	28·9	29·2	
February	,, ..	4	30·1	30·0	29·9	
March	,, ..	4	30·4	30·3	30·5	
April	,, ..	4	31·6	31·3	31·2	
May	,, ..	3	30·7	30·6	30·9	
June	,, ..	..	..	..	..	
July	,, ..	2	26·1	24·7	25·5	Mud value from 3 samples
August	,, ..	4	25·4	23·9	24·8	
September	,, ..	5	25·9	23·9	23·7	
October	,, ..	3	27·2	26·1	26·2	
November	,, ..	3	28·5	28·3	28·4	
December	,, ..	5	28·4	28·2	29·5	Mud value from single sample
January	1953 ..	4	29·0	28·9	29·3	
February	,, ..	4	28·7	28·8	29·3	
March	,, ..	3	30·5	30·2	30·3	

The temperature of bottom water ranges between 23·9° C. and 31·3° C. while that of the bottom muds between 23·7° C. and 31·2° C. in Station I. The corresponding values for Station II are 21·9° C. to 29·7° C. and 22·1° C. to 29·6° C. respectively. In general, there is not much difference between the temperature of the muds and of the overlying water. The temperature is very high between March and May, the highest recorded value being in

TABLE II

Monthly average values of the temperature of the bottom mud and of the overlying water, in degrees centigrade in Station II

(19 Metres)

Month		No. of samples examined	Surface water	Bottom water	Mud
December 1951	..	1	27·9	27·8	28·9
January 1952	..	5	28·0	28·1	28·1
February ,,	..	4	28·8	28·8	28·9
March ,,	..	4	29·7	29·7	29·3
April ,,	..	4	30·0	29·7	29·6
May ,,	..	3	29·8	28·9	29·0
June ,,	..	..	..	..	..
July ,,	..	2	26·6	22·3	22·4
August ,,	..	4	24·6	21·9	22·1
September ,,	..	5	24·8	22·4	22·4
October ,,	..	3	25·7	24·0	24·2
November ,,	..	3	27·3	26·7	26·4
December ,,	..	1	28·0	27·8	27·6
January 1953	..	4	28·0	27·8	27·5
February ,,	..	4	28·2	28·2	28·2
March ,,	..	3	28·9	28·7	28·4

the month of April. Lowest temperatures are observed during the active period of the south-west monsoon. Thus the annual temperature range for bottom water as well as for the muds is about 7·5° C. On a closer examination, it is seen that during the period when the monsoon is active, the differences in temperature between the bottom water and muds are slightly higher than at other times, the muds being somewhat warmer than the overlying water. This is marked particularly in Station I.

Hydrogen-ion concentration.—The pH values of bottom water (Table III) vary between 7·6 and 8·7 and those of muds between 7·6 and 8·1 in Station I and the pH ranges for the water and the muds in Station II are 7·9–8·8 (?) and 7·4–8·1 respectively.

TABLE III

Monthly average values of pH for the mud and bottom water in Stations I and II of the West Hill Sea

Month	Station I			Station II		
	No. of samples examined	Water	Mud	No. of samples examined	Water	Mud
January 1952 ..	5	8·7	8·1	5	8·8 (?)	8·3
February ,, ..	4	8·6	8·1	4	8·7	8·1
March ,, ..	4	8·6	7·7	4	8·7	7·6
April ,, ..	4	8·4	7·6	4	8·6	7·5
May ,, ..	3	8·2	7·6	3	8·4	7·9
June ,, ..	2	8·2	7·7	2	8·3	7·4
July ,, ..	2	8·0	7·9	3	8·0	7·7
August ,, ..	4	7·8	7·7	4	8·1	8·2
September ,, ..	5	7·6	7·9	5	7·9	7·8
October ,, ..	3	8·3	8·1	3	8·4	8·3
November ,, ..	3	8·3	8·1	3	8·4	8·2
December ,, ..	5	8·6	..	..	..	..
January 1953 ..	4	8·4	8·0	4	8·5	7·9
February ,, ..	4	8·5	8·0	4	8·6	7·9
March ,, ..	3	8·5	8·0	3	8·6	8·0

It may thus be seen that there are marked differences in pH values of the muds and the water immediately above. Low pH values are seen between March and September and to a lesser extent in January and February. The pH of the muds is lowest during the monsoon months. The pH values of the water column immediately above the muds also show the same trends, but unlike in the case of muds, the pH does not remain low for a long time.

Chlorinity of the bottom water.—The bottom water does not show much asonal fluctuation in the chlorine content.

TABLE IV

Monthly average values of the chlorinity of bottom water at Stations I and II of the West Hill Sea

Month		No. of samples analysed	Station I	Station II
March	1952	4	19·19	19·06
April	,, ...	4	19·28	19·16
May	,, ...	3	19·35	19·43
June	,, ...	2	19·54	19·19
July	,, ...	3	18·53	19·25
August	,, ...	4	18·35	19·09
September	,, ...	4	19·02	18·90
October	,, ...	3	18·86	18·96
November	,, ...	2	19·36	19·26
December	,, ...	1	18·72	19·28
January	1953	4	17·74	17·84
February	,, ...	4	18·24	18·25
March	,, ...	1	18·74	18·85

The mean annual range both for Stations I and II is about 1·6‰ to 1·8‰. The mean values actually vary between 17·74‰ and 19·54‰ in Station I and between 17·84‰ and 19·43‰ at Station II. Thus compared to the seasonal variations in the surface chlorinity (George, 1954 and Seshappa, 1953 *b*), the variations in the chlorinity of the bottom waters are rather low. The effect of these variations in chlorinity on the character of the bottom muds appears to be negligible. It is only when the chlorine content varies over wide limits as in an estuarine environment from almost fresh-water to typically marine conditions that the character and consistency of the muds are affected.

Nature of the muds.—The percentages of moisture and silt colloidal matter in the muds collected in the different months is given in Table V.

TABLE V

Average monthly values of moisture and silt percentages in mud samples from the Stations I and II of the West Hill Sea

Month		Station I			Station II		
		No. of samples analysed	Moisture %	Silt %	No. of samples analysed	Moisture %	Silt %
December 1951	..	1	72·1	85·9	1	63·5	80·0
January 1952	..	5	73·4	94·4	5	67·5	86·5
February ,,	..	4	71·9	94·6	4	64·4	91·4
March ,,	..	3	70·1	94·5	4	65·7	95·1
April ,,	..	4	69·8	92·4	4	64·8	92·4
May ,,	..	3	68·1	89·6	3	71·7	95·4
June ,,	..	2	63·4	84·9	2	53·1	83·6
July ,,	..	2	65·3	86·9	3	56·5	81·6
August ,,	..	4	69·1	86·3	4	60·8	89·5
September ,,	..	5	71·5	94·1	5	63·0	92·5
October ,,	..	3	73·1	95·4	3	60·1	89·1
November ,,	..	3	69·5	95·4	3	63·7	95·7
December ,,	..	..	..	..	1	67·4	93·9
January 1953	..	2	72·3	94·6	2	63·0	87·9
February ,,	..	4	70·2	93·4	4	62·3	89·6
March ,,	..	2	70·3	96·2	2	66·9	90·0

In Station I, the average moisture content of the mud varies between 63·4% and 73·4% whereas in Station II it ranges between 53·1% and 71·7%. The moisture values for Station II are lower than those for Station I except during May 1952. It may be seen that the moisture content is lowest during the monsoon period and highest during the relatively calm non-monsoon months. The variations in silt colloidal matter like those of the moisture content have shown a definite seasonal trend. Low values for silt content are observed in general during the monsoon months and to a lesser extent in December and January. Due to intense agitation or churning of the entire water column and, with it, the muds, the finer particles are taken up by the water and transported or " broadcast " over a much wider area. The result of this is a reduction in the silt percentage of the bottom muds. It is well known that the moisture-holding capacity of sediments increases with reduction in the particle size and *vice versa* (Sverdrup, Johnson and Fleming, 1942, p. 994). Figure 1 shows clearly the correlation between moisture and silt content of the muds in both Stations I and II. During the monsoon, the mud is composed of relatively coarse particles and hence has a low moisture content. These variations in the consistency of the muds influence to a large extent the release of the inorganic nutrients to the productive zone.

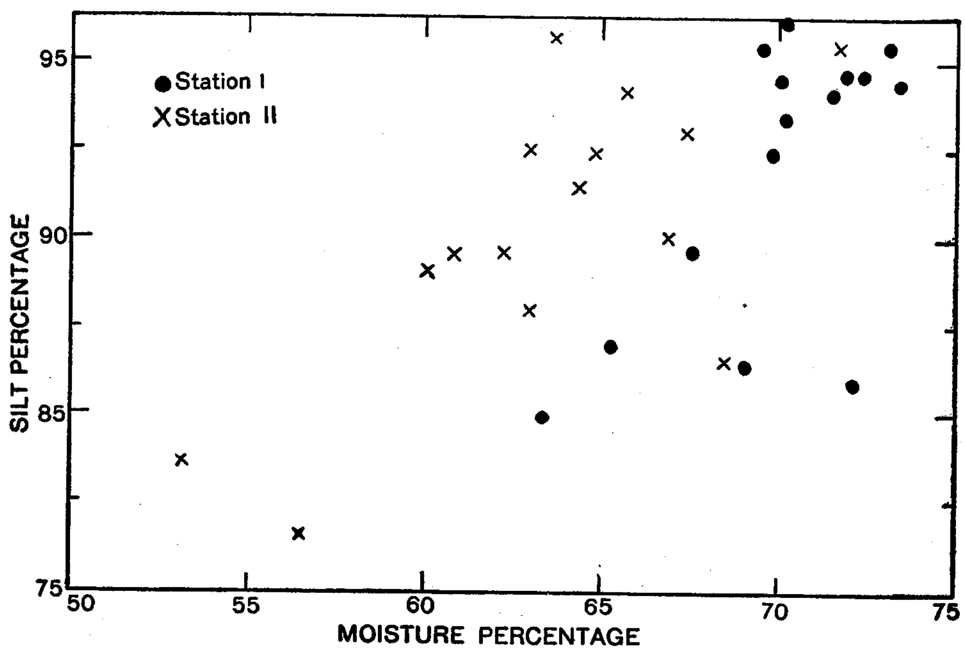

FIG. 1. Correlation between Moisture Content and Silt Content from Stations I and II.

Phosphate

Interstitial and adsorbed phosphates.—The interstitial and adsorbed phosphate values for Stations I and II are shown in Table VI and the seasonal trends are clearly seen in Figs. 2 and 3.

TABLE VI

Monthly average values of interstitial and adsorbed phosphates and also the interstitial phosphate/adsorbed phosphate ratios for the muds from Stations I and II of the West Hill Sea

Month	No. of samples analysed	Station I			Station II		
		Interstitial P. μg. PO_4-P/g.	Adsorbed P. μg. PO_4-P/g.	Interstitial P./Adsorbed P. ratio	Interstitial P. μg. PO_4-P/g.	Adsorbed P. μg. PO_4-P/g.	Interestitial P./Adsorbed P. ratio
January 1952 ..	5	26	47	0·55	25	33	0·76
February ,, ..	4	35	21	1·67	29	16	1·82
March ,, ..	3 (Station I) 4 (Station II)	23	25	0·92	20	24	0·83
April ,, ..	4	17	24	0·71	15	18	0·89
May ,, ..	3	15	27	0·55	33	14	2·36
June ,, ..	2	13	23	0·61	9	10	0·90
July ,, ..	3	15	28	0·54	10	15	0·67
August ,, ..	4	15	40	0·38	16	9	1·78
September ,, ..	5	20	31	0·65	17	8	2·78
October ,, ..	3	22	39	0·56	19	6	3·17
November ,, ..	3	23	32	0·72	20	7	2·86
December ,, ..	1 (Station II only)	..	..	..	24	11	2·18
January 1953 ..	2	14	33	0·42	19	3	6·33
Februray ,, ..	4	19	46	0·41	17	14	1·21
March ,, ..	2	23	40	0·58	17	14	1·21

It may be seen that the lowest values for the interstitial and adsorbed phosphates occur during the monsoon period in the two areas. The seasonal trend is much better represented in Station I than in Station II. April–August is the period of lowest interstitial phosphate in the muds for Station I while for Station II it is April–September with an increase in May. The adsorbed phosphate content is much lower in Station II as compared with Station I and also very low values persist for a longer period in the former area. The ratio of interstitial phosphate to adsorbed phosphate is, in general, much higher in the more offshore 19 metre area (Station II).

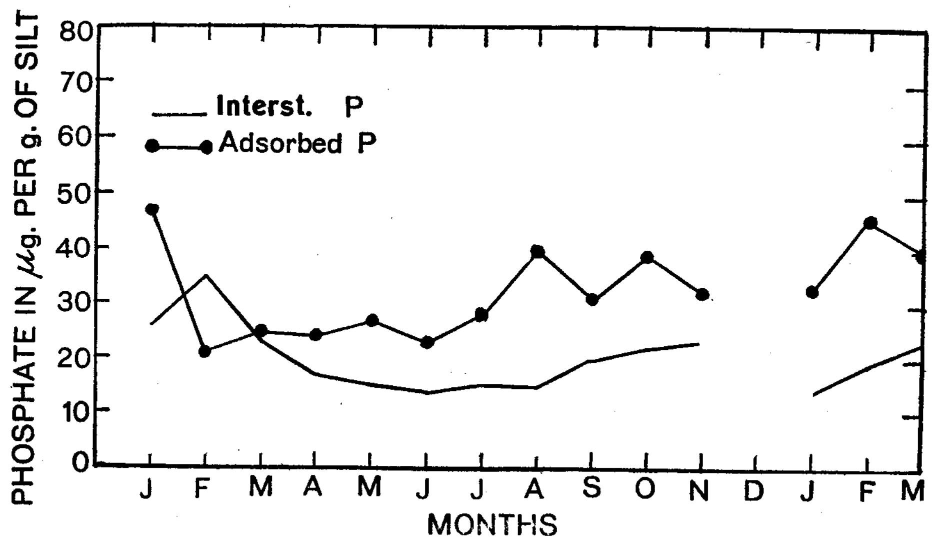

FIG. 2. Monthly Mean Values of Interstitial and Adsorbed Phosphate in the Mud from Station I during the Period January 1952 to March 1953.

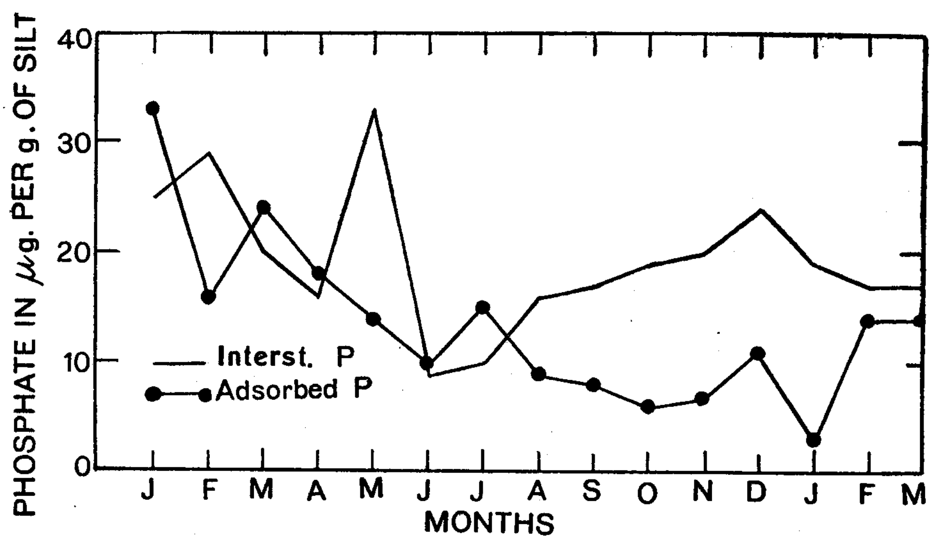

FIG. 3. Monthly Mean Values of Interstitial and Adsorbed Phosphates in the Mud from Station II during the Period January 1952 to March 1953.

Total phosphorus.—The total phosphorus content of the muds (combined organic and inorganic) of the two areas in the various months are given in Table VII.

TABLE VII

Average monthly values of total phosphorus in the muds of Stations I and II of the West Hill Sea

Month		No. of samples examined	Total Phosphorus (μg. PO_4-P/g.)	
			Station I	Station II
January	1952	1	2,500	1,200
April	,,	1	1,500	600
July	,,	1	1,650	1,210
August	,,	3	2,078	1,535
September	,,	2	1,355	920
October	,,	3	1,300	1,173
November	,,	3	1,150	1,260
December	,,	1 (Station II only)	..	1,280
January	1953	2	1,508	1,075
February	,,	3	1,629	1,662
March	,,	2	1,349	1,538

The muds in the inshore area (Station I) are much richer in the phosphorus content than those of the more offshore region (Station II). The mean monthly values for the inshore muds range between 1,150 and 2,500 μg./g. while those for Station II fluctuate between 600 and 1,662 μg./g.

IV. DISCUSSION

Data relating to the various phosphate fractions in the muds of Stations I and II (Table VI) show that the maximum release of phosphates takes place during the monsoon months. Miller (1952) working on the bottom deposits of Biscayne Key, Florida, found that there was an enrichment of the water phosphate regularly every summer from the bottom muds very much as in the present case. He also observed that the transfer of phosphate from sediment to water was accompanied by a slight decrease in pH. It has been found in the present investigations that during the period when the interstitial phosphate values for the muds are low, the pH values are also low (Fig. 4).

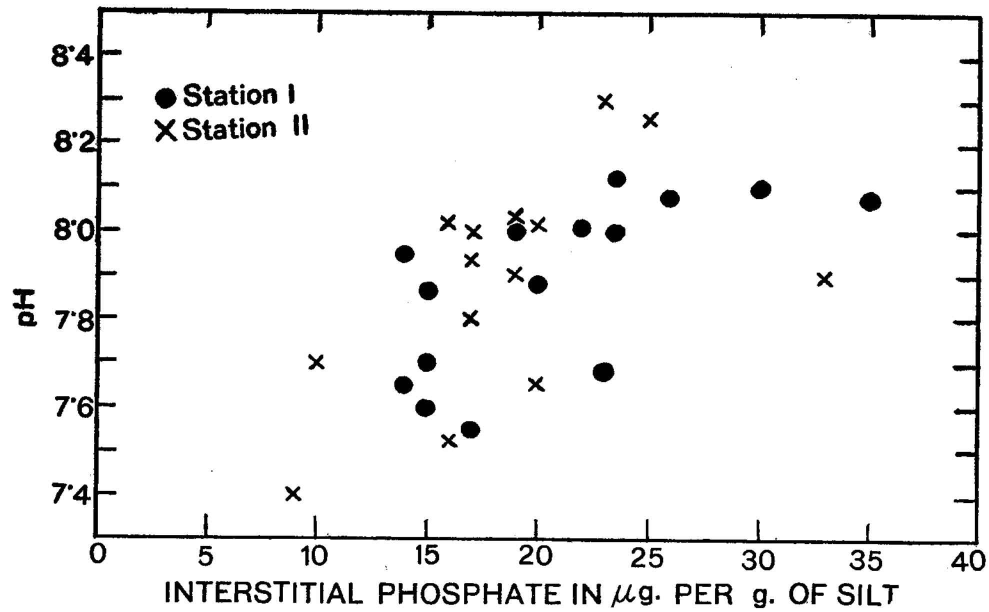

FIG. 4. Correlation between pH and Interstitial Phosphate of Mud Samples from Stations I and II.

The interstitial phosphates are, in general, very low during the period of the monsoon and the reduction in this phosphate fraction is due to the leaching effect on the immediate surface layers. The degree of leaching is, to a large extent, dependent on the *permeability* of the mud surface. The permeability of the mud in turn, is determined by its porosity, particle size and " compaction " and is a measure of the ability of the water to circulate through it (Sverdrup *et al.*, *loc. cit.*, p. 933). As stated earlier, the intense agitation or churning during the monsoon helps to transfer the phosphates from the interstices of the mud to the overlying water. It could also be seen that while there is reduction in the values for interstitial phosphates, the phosphate content of the bottom water in both the stations increases considerably during the monsoon (Table VIII).

The adsorbed phosphate shows reduction in concentration similar to the interstitial phosphate during the monsoon period. According to Rochford (1951, p. 37) there appears to be an equilibrium between the interstitial and adsorbed forms of phosphate. So with the progressive removal of interstitial phosphate more and more of adsorbed phosphate should be brought into the interstices and thence to the water column. During the non-monsoon months the permeability of the muds is very low in view of the high silt content

TABLE VIII

Average monthly values of inorganic phosphate content in the bottom water at Stations I and II of West Hill Sea

Month	μg. PO_4-P/L of water	
	Station I (4 Metres)	Station II (19 Metres)
January 1952	10	7
February ,, ...	13	8
March ,, ...	12	10
April ,, ...	9	8
May ,, ...	9	10
June ,, ...	12	12
July ,, ...	53	61
August ,, ...	101	83
September ,, ...	107	58
October ,, ...	63	56
November ,, ...	22	22
December ,, ...	23	10
January 1953	11	5
February ,, ...	11	8
March ,, ...	15	11

and maximum " compaction ". This results in the retention of large quantities of phosphates in the interstices of the muds while the overlying water has low concentration of phosphates.

One of the possible sources of phosphate in the bottom muds off the Malabar Coast as stated by Seshappa (1953 *a*) is the run-off during the monsoon months bringing with it fine particles of laterite containing a lot of adsorbed phosphate. The sources of phosphate regeneration in the local turnover are also of great importance though the details relating to this aspect will not be discussed here. An important factor affecting the local turnover in the West Hill Sea must, however, be mentioned, namely, a large-scale mortality of bottom animals in the inshore regions at the commencement of the monsoon (Seshappa, 1953 *b*). Such a mortality must naturally result in a chain of events leading to a considerable increase in the phosphates of the bottom deposits the bacteria playing a dominant role in these changes (Stephenson, 1949; Barnes, 1954; Harvey, 1955).

V. Summary

Data have been collected on the temperature, pH, silt colloidal matter, moisture and phosphate content of mud samples from two selected stations of the West Hill Sea along the Malabar Coast.

The variations in the several factors have revealed a distinct seasonal trend, the values being, in general, low for all the factors during the monsoon months.

The bottom muds contain large quantities of interstitial and adsorbed phosphates in the non-monsoon period. During the monsoon there is a rapid release of phosphates into the overlying column of water.

The factors associated with the monsoon release of phosphates from the muds are examined.

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