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Seasonal Variation of the Environmental Parameters along Fort Cochin Beach

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Monthly observations on heterotrophic bacteria, organic carbon, temperature, salinity, dissolved oxygen, inorganic phosphate, nitrate, nitrite and ammonia from surface water and from water table level during high tide, mid tide and low tide were carried out in the Fort Cochin beach for a period of one year. Also, monthly observations on heterotrophic bacteria, organic carbon and temperature were carried out for the same period from sand during the three tidal levels at surface and water table level. The study showed that organic carbon in sand controlled the bacterial population to a great extent during high tide at surface and during low tide at water table level. Step-up multiple regression analysis showed that in water the interaction effect of inorganic phosphate and ammonia and that of ammonia and temperature were the most important parameters controlling the bacterial production whereas in the sand at the surface, temperature-organic carbon interaction effect was the controlling parameter. The results of the Q-mode analysis are also presented.

Key words: Environmental parameters, heterotrophic bacteria, seasonal changes, Fort Cochin beach

The importance of heterotrophs in the marine beach environment has received only very little attention. The sandy beach of Fort Cochin regularly receives dead and decaying fishes, decaying weeds of salvinia, heavy load of sewage and terrigenous debris. The present study is on the numerical abundance and seasonal variations of heterotrophic bacteria in relation to environmental parameters in the sandy beach of Fort Cochin. The effect of these on the ecology has not been fully investigated so far. Some studies have been made on these aspects (Trivellian *et al.*, 1970; Ansell *et al.*, 1972; Gore & Singbal, 1973; Dwive, 1973; Achuthankutty *et al.*, 1978; Nair *et al.*, 1979; Wafar *et al.*, 1980; Palaniyappan & Krishnamoorthy, 1985; Kannan & Vasantha, 1986), but as far as the ecology of the extensive sandy beaches on the east and west coasts of India are concerned, there is a dearth of information.

Materials and Methods

Monthly samples of sand from surface and water table level (WTL) from high, mid and low tide levels were collected in sterile petri dishes. Surface water and WTL water from the three tidal levels were also collected in sterile glass bottles. These samples were transported within three hours to the laboratory aseptically, for isolation and enumeration of heterotrophic bacteria. Temperature was recorded at the sampling time. Standard methods were adopted for the analysis of heterotrophic bacteria (Wakeel & Riley, 1957) and chemical parameters such as salinity, dissolved oxygen, inorganic phosphate, NO_3-N, NO_2-N and ammonia (Grasshoff *et al.* 1983). The data were subjected to statistical analysis through Tuckeys test of additivity to see if the additivity of the treatment effects of the parameters is satisfied. Suitable transformation of data was applied (Tuckey, 1949) and the analysis were carried out on the transformed data unless it is mentioned otherwise, because in factor analysis (Rummel, 1975) and regression analysis (Sokal & Rholf, 1981), the normalization of original data and normalization of the log values of the data respectively, are used.

Three way analysis of variance (Federer, 1967) has been applied to study the significance of the difference between parameters, between tidal levels and between months and also the first order interaction effects among these factors. When the tidal fluctuations were found to be not highly significant, the data were pooled over the three tidal levels and step-up multiple regression model was applied to select the best combination of the parameters to predict the bacterial density and also to delete the most insignificant parameters (Snedecor & Cochran, 1967) based on the significance of the test statistic t for each regression coefficient.

Q-mode and R-mode factor analysis (Angel & Fasham, 1973) using row and column normalization of data and using varimax rotation to simple structure (Gutman, 1954 & Kaiser, 1958) for unique grouping of the parameters and months, respectively were carried out. Skewness and kurtosis characteristics of the factor score distribution were also studied (Snedecor & Cochran, 1967). The percentage distribution of the parameters was studied for comparative purposes. Seasonal dependency in the distribution was also considered.

Results and Discussion

Based on three way analysis of variance, it was found that bacterial counts in sand did not differ significantly between surface and bottom as well as between tidal levels ($P=0.05$) but differed significantly between months $F_{(11, 110)} = 5.3776$, $P<0.05$). Significant first order interaction effect was observed between positions/tidal levels and parameters ($F_{(10,110)} = 15.8967$, $P\leq0.05$) as well as between seasons and parameters ($F_{22,110} = 6.5733$, $P\leq0.05$). No significant first order interaction effect between positions/tidal levels and seasons was observed ($p\geq0.05$). Maximum density (5000 g^{-1}) was in May during high tide water table level, (WTL) and minimum (2000 g^{-1}) in February during high tide and mid tide WTL, and distribution was highly consistent irrespective of tidal variation (Figs. 1-6). On pooling the data over all the tidal levels it was observed that heterotrophic bacteria occurred more abundantly at the bottom than at the surface with less variation at the bottom (coefficient of variation, CV%=2.8806) than at the surface (CV%=2.0044, Table 1). Organic carbon was high (6.78 $mg.g^{-1}$) in May and low (0.613 $mg.g^{-1}$) in February at surface during high tide. Very low values were observed in November also at high tide WTL. On

Table 1. Average (GM). Standard deviation (SD) and coefficienty of variation (C.V. %) of heterotrophic bacteria and correlation (r) of the parameters

Sample	Parameter	G.M.	SD	C.V. (%)	*r*
Sand surface	H. bacteria	1.1960	0.0328	2.9944	
	Temperature	1.5197	0.0444	2.9245	-0.3436
	Organic carbon	0.4092	0.0952	23.2676	0.2467
Sand bottom	H. bacteria	1.2382	0.0357	2.8806	
	Temperature	1.4535	0.0173	1.1806	-0.0923
	Organic carbon	0.4614	0.1283	27.8089	0.4223
Water	H. bacteria	1.2251	0.0389	3.1760	
	Temperature	1.4589	0.0200	1.3713	-0.2077
	Salinity	1.4078	0.0821	5.8322	0.0033
	Dissolved oxygen	0.6962	0.0422	6.0603	-0.2404
	PO_4 - P	0.6909	0.2193	31.7485	-0.0404
	NO_3 - N	0.5510	0.2503	45.4234	-0.0399
	NO_2 - N	0.1218	0.0714	58.6315	0.1021
	NH_4 - N	0.1115	0.0602	54.0180	-0.1542

Table 2. Q-mode factor analysis for grouping of water quality parameters

Factors	Parameters	Maximum factor loading	Eigen (λ) values	Closeness ratio	Variability explained	% variability explained
(a) High tide						
1	Salinity	-0.8141				
	Diss. Oxygen	-0.7971	6.645	83.07	3.2729	40.912
	Temperature	-0.7449				
	H. bacteria	-0.8153				
2	NO_3 - N	-0.8489	0.5579	90.04	1.3204	16.505
3	NH_4 - N	-0.7898	0.3613	94.43	1.2405	15.506
4	PO_4 - P	-0.8460	0.2759	97.89	1.2824	16.030
5	NO_2 - N	0.6923	0.1397	99.64	0.8550	10.687
(b) Mid tide						
1	Ammonia	-0.7816	6.914	86.43	1.4083	17.6035
2	NO_3 - N	-0.8166	0.4602	92.18	1.4390	17.9877
3	NO_2 - N	-0.7443	0.3197	96.18	1.1888	14.8595
4	PO_4 - P	0.7304	0.1594	98.17	1.1207	14.0085
5	Salinity	-0.7458				
	Dis. Oxygen	-0.7118	0.1151	99.61	2.8122	35.1621
	Temperature	-0.6956				
	H. bacteria	-0.7678				
(c) Low tide						
1	Temperature	-0.5478				
	Ammonia	-0.8511	6.984	87.30	2.0922	26.1524
2	PO_4 - P	0.8374				
	NO_3 - N	0.8821	0.5405	94.06	2.5805	32.2560
3	NO_2 - N	0.8034	0.2562	97.25	1.6232	20.2900
4	Salinity	-0.5881				
	Dis. Oxygen	-0.5968	0.1595	99.25	1.6402	20.5021
	H. bacteria	-0.5709				
(d) Surface water						
1	Ammonia	-0.8974				
	Salinity	-0.8786				
	Dis. Oxygen	-0.8315	6.959	86.98	4.045	50.566
	Temperature	-0.8243				
	H. bacteria	-0.7676				
2	PO_4 - P	0.8516				
	NO_3 - N	0.8218	0.5873	94.33	2.2606	28.2662
3	NO_2 - N	0.8523	0.2752	97.77	1.4958	18.6978

combining all the tidal data, it was observed that level of organic carbon was higher at the bottom (GM=0.4614 $mg.g^{-1}$) with higher variation (CV%=27.8089) than at the surface (GM=0.4092 $mg.g^{-1}$) (Table 1).

Pattern of distribution of temperature was similar to that of bacterial distribution except at high tide WTL, with maximum temperature (37°C) in November at high tide WTL and minimum (28°C) in May at low tide WTL and with higher average (GM=1.5197°C) and higher variation (CV%=2.9245) at surface than at the bottom (GM=1.4535°C, CV%=1.1876). Bacterial abundance had high negative correlation with temperature at surface (r=.0.3436) than at the bottom (r=-0.0923) whereas its relation with organic carbon was the reverse at surface (r=-0.2467) and at the bottom (r=0.4226). Level of heterotrophic bacteria was observed to be more a function of organic carbon at

Table 3. R-mode factor analysis for grouping months in the case of water quality parameters

Factors	Parameters	Maximum factor loading	Eigen (λ) values	Closeness ratio	Variability explained	% variability explained
(a) High tide						
1	November	-0.5796	11.71	97.60	4.0042	33.368
	January to	-0.7245 to				
	May	-0.5357				
2	June to	-0.5920 to				
	October	-0.7972	0.1544	98.89	4.3723	36.44
	December	-0.6346				
(b) Mid tide						
1	June	-0.6836				
	July	-0.6652	11.77	98.07	3.9759	33.1279
	September	-0.6536				
2	October	0.57049				
	November	0.63129				
	February	0.70635	0.0954	98.86	4.0298	33.58
	March	0.67924				
3	August	0.5999				
	December	0.6085				
	April	0.7020	0.0935	99.64	3.9435	32.86
	May	0.6818				
(c) Low tide						
1	June to	-0.8333				
	January	-0.7232				
	April	-0.7100	11.69	97.44	6.6667	56.567
	May	-0.7704				
2	February	0.8288				
	March	0.8289	0.2237	99.30	4.9067	40.889
(d) Surface water						
1	June to	-0.8272				
	October	-0.6868	11.76	97.97	5.4163	45.1357
	December	-0.6879				
2	November	0.6700				
	January to	0.7064 to	0.1585	99.79	5.6156	46.7966
	May	0.7954				

high tide and low tide WTL than temperature.

The predictive regression mode fitted for surface was Y=0.000125176 - $0.311241X_1$ + 0.19513X2 - $0.0007505X_1{*}X_2$, where X_1 = temperature, X_2 = organic carbon and $X_1{*}X_2$=interaction between the parameters X_1 = and X_2. This model explains only 7.58% of the seasonal/tidal variations in the bacterial density distribution and it is found to be highly significant ($F_{(3, 32}$=1.9574, P≤0.05).

The predictive regression model for the bottom sample was Y=0.10849 + 0.002810485 X_1 + $0.2588289X_2$ - $0.3764937X_1{*}X_2$ where X_1, X_2 and $X_1{*}X_2$ were same as for the surface samples. This model could explain 25.18% of the seasonal/tidal variations in the bacterial distribution with high significance (4.9270, P≤0.05). A similar relation has been observed elsewhere (Dale, 1974 and Achuthankutty *et al.*, 1978).

On applying analysis of variance to the distribution of heterotrophic bacteria and

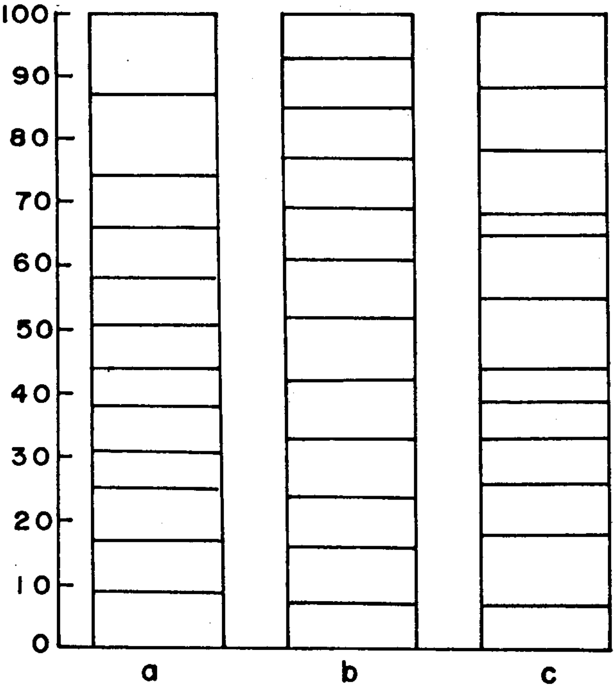

Fig. 1. Percentage distribution of heterotrophic bacteria (a), temperature (b) and organic carbon (c) in the surface water during high tide.

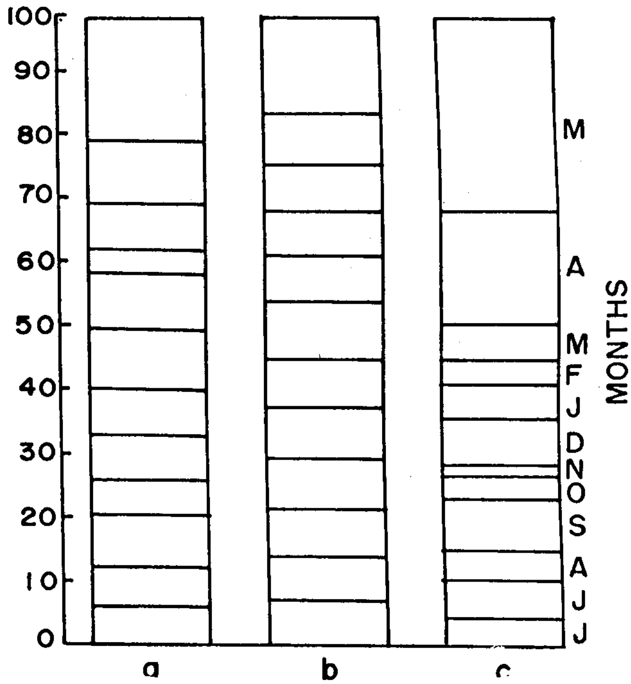

Fig. 2. Percentage distribution of heterotrophic bacteria (a), temperature (b) and organic carbon (c) in sand during high tide.

water quality parameters, it was observed that they differed significantly between months ($F_{11, 231}$)=5.05328, $P \leq 0.05$), but between tidal levels, the difference was less significant ($F_{3, 231}$)=2.11309, $P \leq 0.05$). Heterotrophic bacteria was abundant (4700 ml^{-1}) in May at high tide WTL and in April, during mid tide and less abundant (1800 ml^{-1}) in February at low water table level. Bacterial distribution was more uniform at surface than at other tidal levels (independent of tidal variations generally). Average density was 2.450 ml^{-1} (GM) with 3.1760% seasonal/tidal variations. Temperature, salinity and dissolved oxygen were distributed with very low variations and in a pattern similar to that

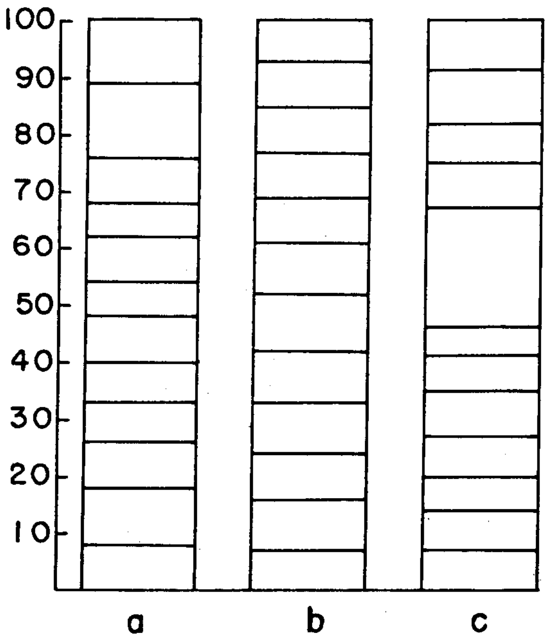

Fig. 3. Percentage distribution of heterotrophic bacteria (a), temperature (b) and organic carbon (c) in surface water during mid tide.

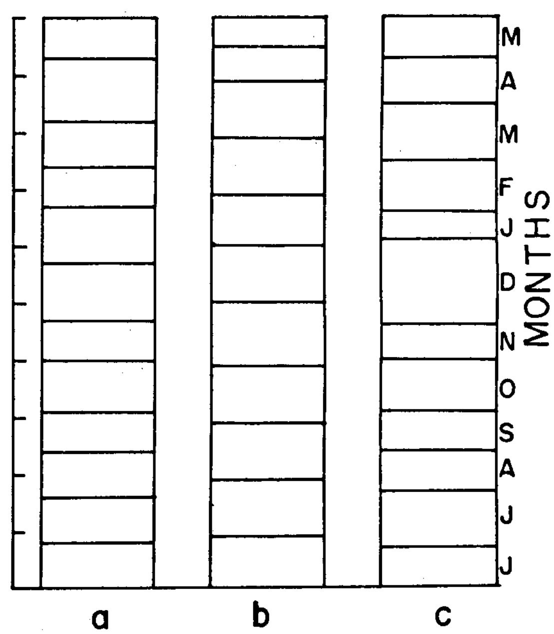

Fig. 4. Percentage distribution of heterotrophic bacteria (a), temperature (b) and organic carbon (c) in sand during mid tide.

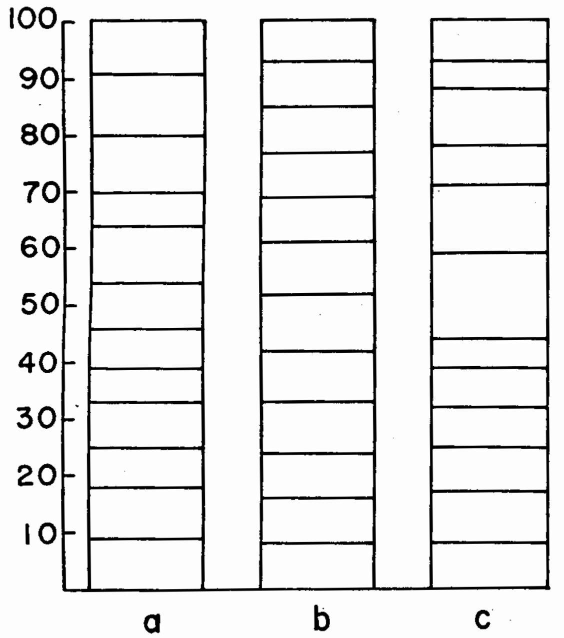

Fig. 5. Percentage distribution of heterotrophic bacteria (a), temperature (b) and organic carbon (c) in surface water during low tide.

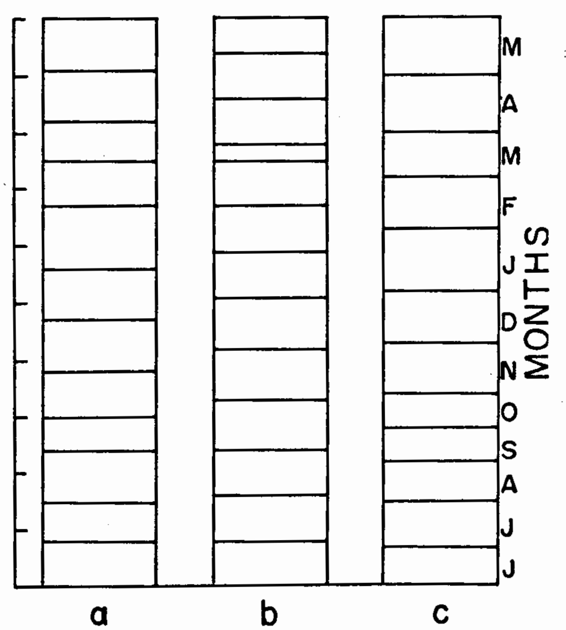

Fig. 6. Percentage distribution of heterotrophic bacteria (a), temperature (b) and organic carbon (c) in sand during low tide.

of bacterial distribution (Figs. 7-10). Nutrients were distributed with high seasonal variations (CV ranged from 31.74% to 58.63%, Table 1).

The heterotrophic bacteria showed moderate negative correlation with dissolved oxygen in the study area (Table 1). But Morthy (1981) observed a situation which was contrary to this. Aerobic heterotrophs are highly tolerant to anoxic conditions because of their facultative or microaerophilic nature. Moderate negative correlation was observed between heterotrophic bacteria and temperature in this study. But significant positive correlation was observed by Chandrika & Nair (1994). Nedwell & Floodgate (1971) also found a positive correlation of heterotrophic bacteria in relation to some environmental parameters and concluded that temperature was not a limiting factor on the bacterial population

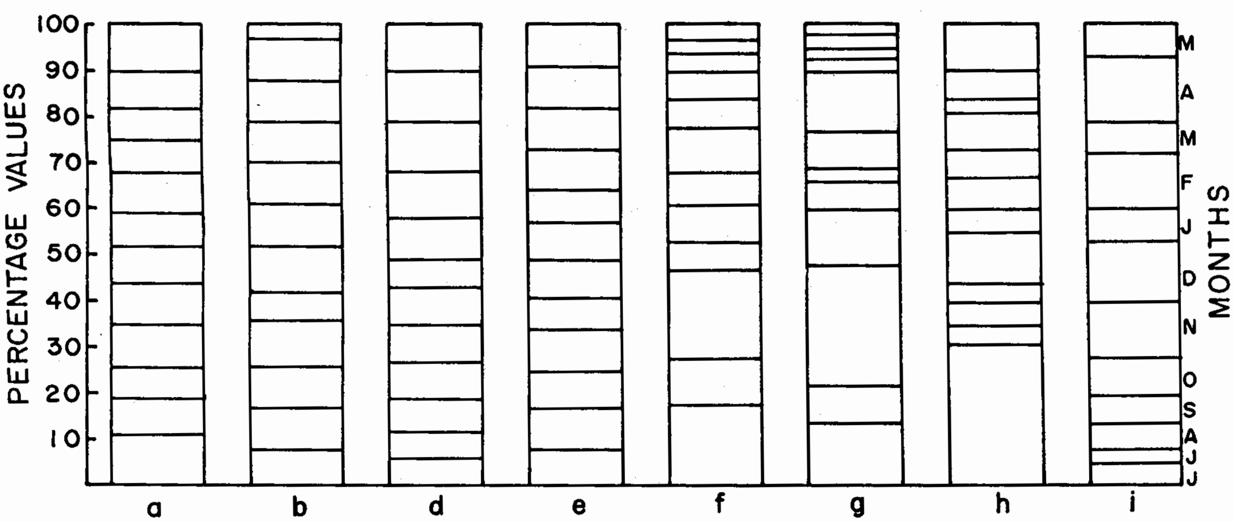

Fig. 7. Percentage distribution of heterotrophic bacteria (a), temperature (b) and organic carbon (c), salinity (d), dissolved oxygen (e), PO_4-P (f), NO_2-N (g), NO_3-N (h) and Ammonia (i) in surface water.

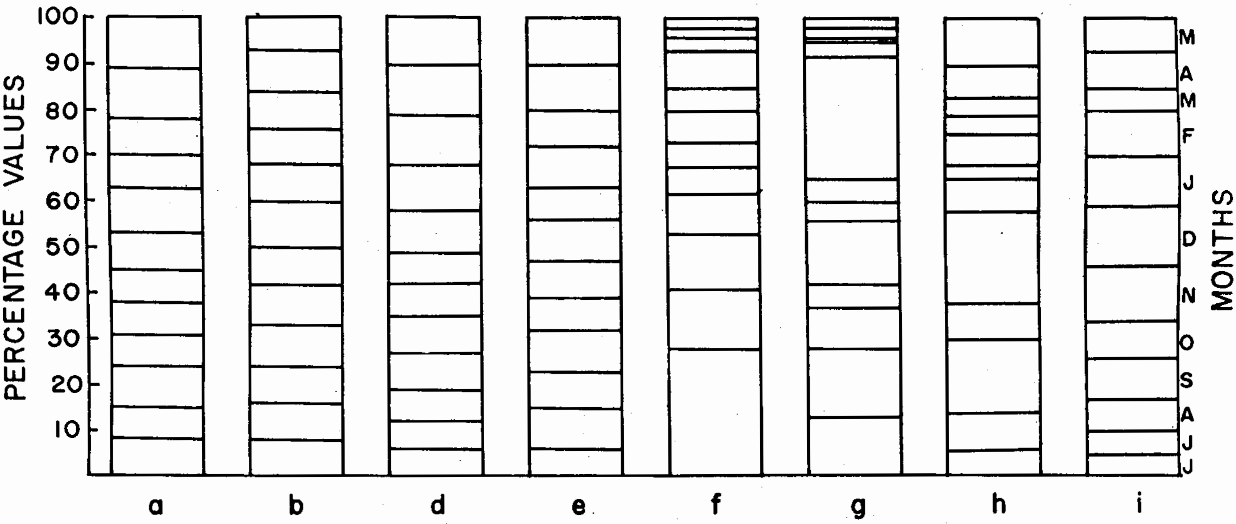

Fig. 8. Percentage distribution of heterotrophic bacteria (a), temperature (b), organic carbon (c), salinity (d), dissolved oxygen (e), PO_4-P (f), NO_2-N (g), NO_3-N (h) and Ammonia (i) in the water table level during high tide.

even during summer months. The negative association between temperature and density of heterotrophic bacteria showed the nature of the marine bacteria.

On comparing the bacterial density and other water quality parameters between months, between tides and their interaction effect, it was found that there was significant difference between the values of these parameters ($F_{(7,231)}$=2358.60, P≤0.05), between months ($F_{(11,231)}$=5.0533, P≤0.05) and less significant difference between tidal levels ($F_{(3,231)}$=2.1131, P≤0.05). The variations in the parameter values are due to tidal variations as indicated by high F value ($F_{(21,231)}$=8.2209, P≤0.05) for parameter-tide interaction effect and also due to seasonal fluctuations as indicated by high value for parameter-season interaction effect ($F_{77,231}$)=9.0665, P≤0.05). But tidal variations in the different months are only negligible ($F_{(33,231)}$=0.6271, P≥0.05). Among the parameters, higher seasonal variations have been obtained for NO_2-N (C.V%=58.63), NH_4-N (C.V.%=54.018) and NO_3-N (C.V.%=45.4234) and least for temperature (C.V.%=1.3713). Among the input

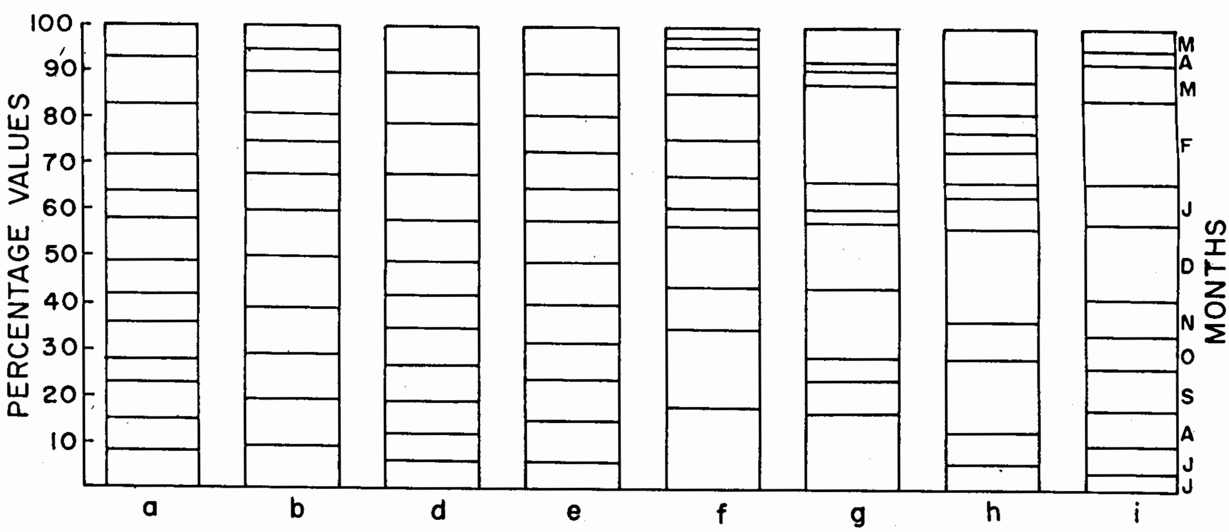

Fig. 9. Percentage distribution of heterotrophic bacteria (a), temperature (b), organic carbon (c), salinity (d), dissolved oxygen (e), PO_4-P (f), NO_2-N (g), NO_3-N (h) and Ammonia (i) in the water table level during mid tide.

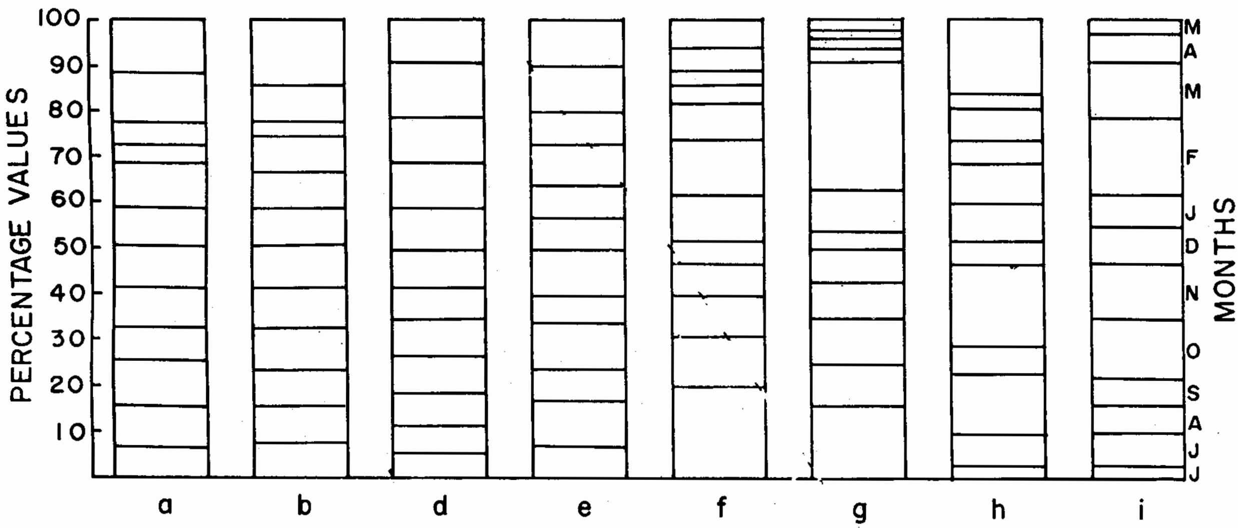

Fig. 10. Percentage distribution of heterotrophic bacteria (a), temperature (b), organic carbon (c), salinity (d), dissolved oxygen (e), PO_4-P (f), NO_2-N (g), NO_3-N (h) and Ammonia (i) in the water table level during low tide.

parameters, except salinity and NO_2-N, all others were negatively correlated with heterotrophic bacteria (Table 1).

Regarding the predictive multiple regression model for bacteria from water, the fitted equation is $Y=0.05571-0.0224088X_1$ +

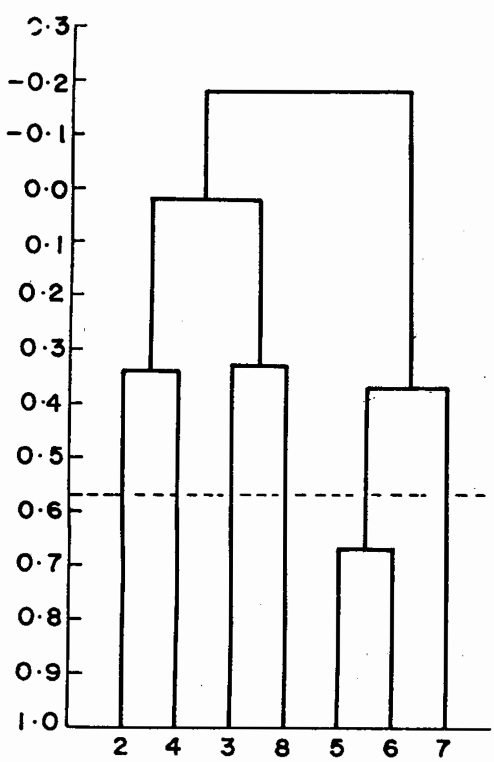

Fig. 11. Dendrogram showing the relationship between water quality parameters, temperature (2), salinity (3), dissolved oxygen (4), PO_4-P (5), NO_2-N (6) NO_3-N (7) and NH_4-N (8) in surface water.

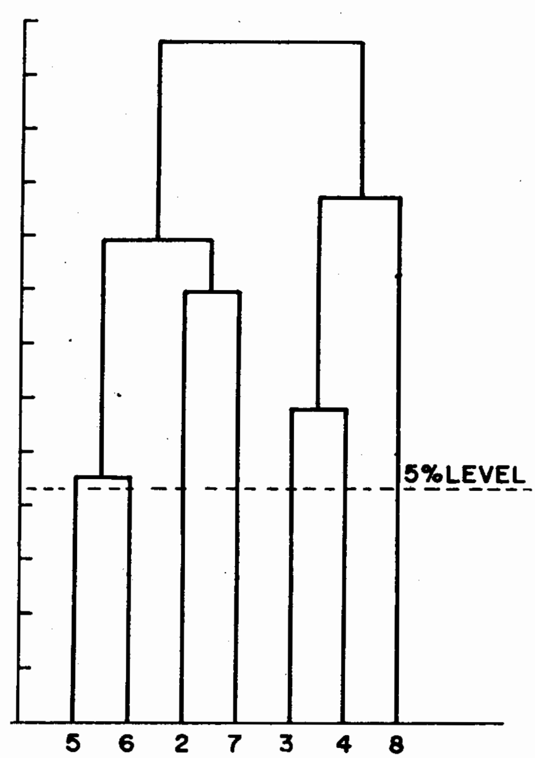

Fig. 12. Dendrogram showing the relationship between water quality parameters, temperature (2), salinity (3), dissolved oxygen (4), PO_4-P (5), NO_2-N (6) NO_3-N (7) and NH_4-N (8) in the water table level during high tide.

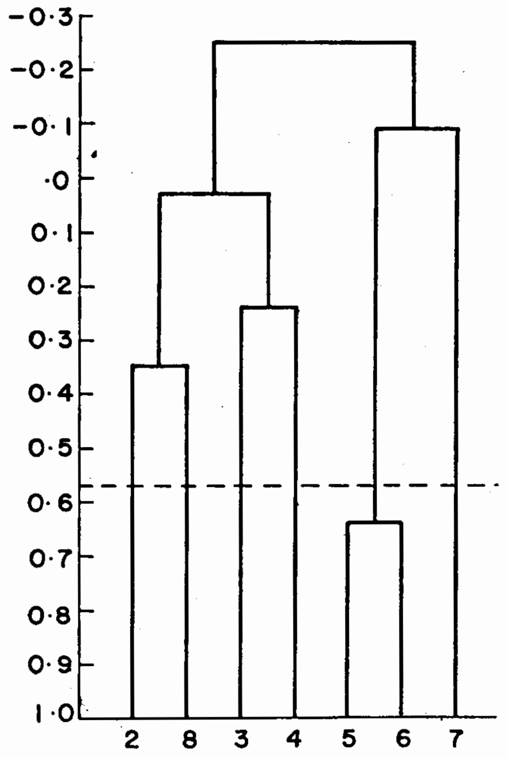

Fig. 13. Dendrogram showing the relationship between water quality parameters, temperature (2), salinity (3), dissolved oxygen (4), PO_4-P (5), NO_2-N (6) NO_3-N (7) and NH_4-N (8) in the water table level during mid tide.

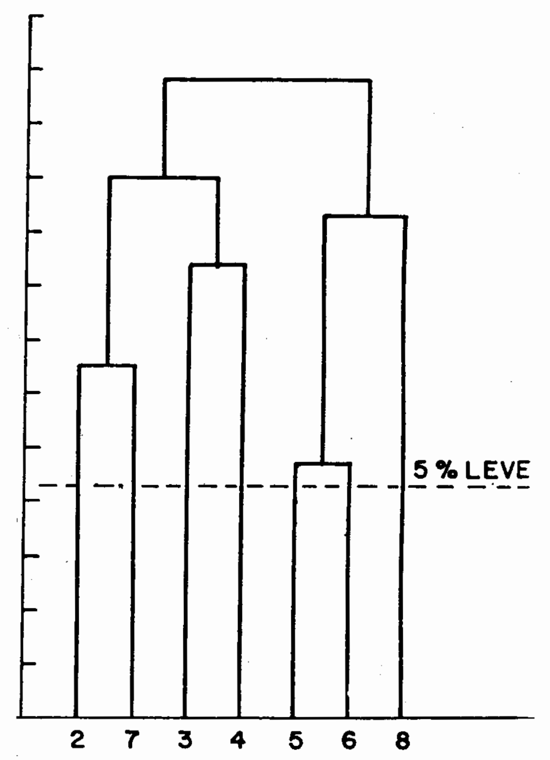

Fig. 14. Dendrogram showing the relationship between water quality parameters, temperature (2), salinity (3), dissolved oxygen (4), PO_4-P (5), NO_2-N (6) NO_3-N (7) and NH_4-N (8) in the water table level during low tide.

$0.1123648X_2 - 0.243901X_3 + 0.670382X_1{*}X_2 - 0.1682789X_1{*}X_3 + 0.420311X_2{*}X_3$, where X_1 = phosphate, X_2=ammonia and X_3 = temperature and * denotes the first order interaction effects of the above parameters taken in pairs. This model could explain about 27.7% of the seasonal variations in the bacterial distribution ($F_{(6,41)}$=4.0085, $P \leq 0.05$).

The relative importance of the predictive parameters could be graded as (PO_4 - P*ammonia) > (ammonia * temperature) > temperature > PO_4-P > PO_4-P*temperature. All other parameters were found to be insignificant in this relation. The predicted values could be made more precise by incorporating other water quality parameters such as silicate and turbidity of water and biological parameters such as phytoplankton and zoo-plankton and their first order interaction effects with silicate and other nutrients. This method considers 128 models including all possible combinations of the 7 parameters and in each of these, absolute values, log transformed and square root transformed values of the input parameters were also considered. Among these, the one given above gave the maximum explained variability.

An attempt had been made to group the parameters as well as the months which have similar distribution patterns. Varimax rotation to simple structure has been adopted for uniqueness of the factor loadings and factor scores. Q-mode analysis showed that in the surface water and during high tide, the first prominent group included temperature, salinity, dissolved oxygen and bacteria whereas during mid tide and low tide, that group became the most insignificant. Similarly PO_4-P and NO_3-N were grouped together in the second factor group in the surface water and low tide with high positive factor loading while they were grouped in the second (NO_3-N) and fourth group (PO_4-P) with high negative and positive factor loadings during high tide and mid-tide respectively (Table 2).

Based on R-mode analysis, only one significant factor group of months including post and pre-monsoon seasons during high tide, low tide, mid tide and surface water, with high negative factor loading in each case, was identified. In each case, first two factor groups formed the differential factor groups explaining at least 50% of the total variations and were with opposite signs except during high tide, implying that conditions prevailing during pre-monsoon affect the bacterial production in a different way when compared with other seasons of the year (Table 3). The concentration of PO_4-P and NO_3-N increased from June to September. October and November showed the transitional period; thereafter the concentration decreased from December to May and slowly revived back to the normal concentration whereas in the case of NO_2-N and NH_4-N, the variation was highly irregular and almost the reverse. This change in the concentration was observed to be a gradual and continuous process as evident from the highly skewed factor score distribution of the parameters at all tidal conditions.

The environmental parameters are correlated and a dendrogram showing the significant clusters are drawn (Fig.11-14). In all cases of water samples namely surface water and WTL water at three tidal levels, it was invariably shown that PO_4-P and NO_3-N formed the highly correlated group of environmental parameters indicating that the heterotrophic bacteria were biochemically complex organisms. It further showed that they had the capacity to adapt themselves to different environmental conditions.

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