

DISTRIBUTION OF NUTRIENTS IN THE SHELF WATERS OF THE ARABIAN SEA ALONG THE WEST COAST OF INDIA*

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The paper presents a descriptive account of the distribution of phosphates, silicates and nitrates in the shelf waters of Arabian Sea along the West Coast of India including a brief mention about the hydrographical features and their relationship with the former during the period September to December 1963. The results indicate marked variations through different periods, in nutrients and other hydrographical features. Two distinct environmental conditions are apparent in the shelf waters from the nutrients point of view, characterised by nutrient deficient surface layers in the post-monsoon period and nutrient rich surface layers in the south-west monsoon period. These conditions are well reflected in the corresponding variations of the hydrographical features. It is also observed that the concentrations of the nutrients show a general decreasing trend from south to north. The distribution of the elements are more influenced by a phenomenon similar to upwelling, occurring during the closing phase of the south-west monsoon. The regional differences in the concentrations of the nutrients along the coast during this period, are attributed to the varying intensities of this upwelling like phenomenon. Post-monsoon period is characterised by more vertical stability of the waters and uniform distribution of the properties. A significant feature of the nutrient components of the near shore environment (less than 15 miles) is their constancy through different periods; the values are relatively high throughout. Probable factors controlling the vertical and horizontal distribution of nutrients are indicated.

INTRODUCTION

The significance of the nutrients in the sea, especially of phosphates, silicates and nitrates, is well recognised, in understanding the diversities exhibited in the distribution of marine populations in space and time and also in characterizing the water masses and their movements in conjunction with other physical oceanographic parameters. West Coast of India supports a rich fishery of varied intensities in different seasons and in view of this fact it is felt that the study of the nutrient levels in different periods of the year, apart from the regular hydrographic conditions (temperature, salinity and oxygen) may also help in understanding the seasonal changes in fisheries. The present work was undertaken as part of the studies on the nutrient distribution in the Indian Ocean under the Indian Programme of the International Indian Ocean Expedition.

The present paper deals with the results based mainly on the nutrient data of the shelf waters along the West Coast of India within which the major fisheries

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of sardine and mackerel are known to occur. The relationship of the nutrients to other hydrographical features has also been briefly discussed. Among the previous investigations on nutrients, especially in the inshore waters, mention may be made of studies by George (1953), Rao (1957), Subramanian (1959), Seshappa and Jayaraman (1956), Jayaraman and Seshappa (1957). The present work covers three regions along the West Coast from Quilon to Ratnagiri giving the variations in monsoon and post monsoon seasons in 1963.

MATERIAL AND METHODS

Collections were obtained during the regular oceanographic cruises of R. V. VARUNA from three selected regions: 1. Off Quilon, 2. Off Mangalore, 3. Off Ratnagiri across the continental shelf falling in line with oceanographic programme of the Central Marine Fisheries Research Institute. Collections were mostly made up to the edge of the continental shelf except on some occasions when a few samples were collected beyond the shelf. Sections covered and station locations and periods are given in Fig. 1. Only parts of the sections comprising the station locations wherein water sampled for nutrients are represented in the map. The water samples were preserved by freezing at -10°C for subsequent analysis at the shore laboratory at Cochin. In the laboratory the samples were brought to the room temperature quickly with the aid of a thermostatic water bath, before analysis.

Inorganic phosphates:—Phosphates were estimated by the method of Deniges as adopted by Wooster and Rakestraw (1951). Absorbance was measured at $700\text{ m}\mu$ using SP 500 Unicam Spectrophotometer. Phosphate values are not corrected for salt error.

Silicates:—The method of Wandenbulcke (1923) as adopted by Robinson and Thompson (1948) was used. Absorbance was measured at $404\text{ m}\mu$ as suggested by Barnes (1960). Comparisons were made with potassium chromate standards buffered with borax.

Nitrates:—Nitrates were estimated by the technique of Mullin and Riley (1955) as described by Barnes (1960). The absorbance of the resulting azo-dye was measured at $524\text{ m}\mu$.

RESULTS

The sections covered in a particular region during the two different periods (monsoon and post-monsoon) are designated as 'a' and 'b'.

Sections Off Quilon:

Section 'a':—(Between Lat. $8^{\circ}59'$ N, Long. $75^{\circ}59'$ E and Lat. $9^{\circ}11'$ N, Long. $76^{\circ}22'$ E) covered in the month of September 1963,

During this period, the phosphate content of the upper 10 m in the inshore region (less than 20 miles from the coast) is high ranging from 0.54 to 1.4 $\mu\text{g. at/L}$

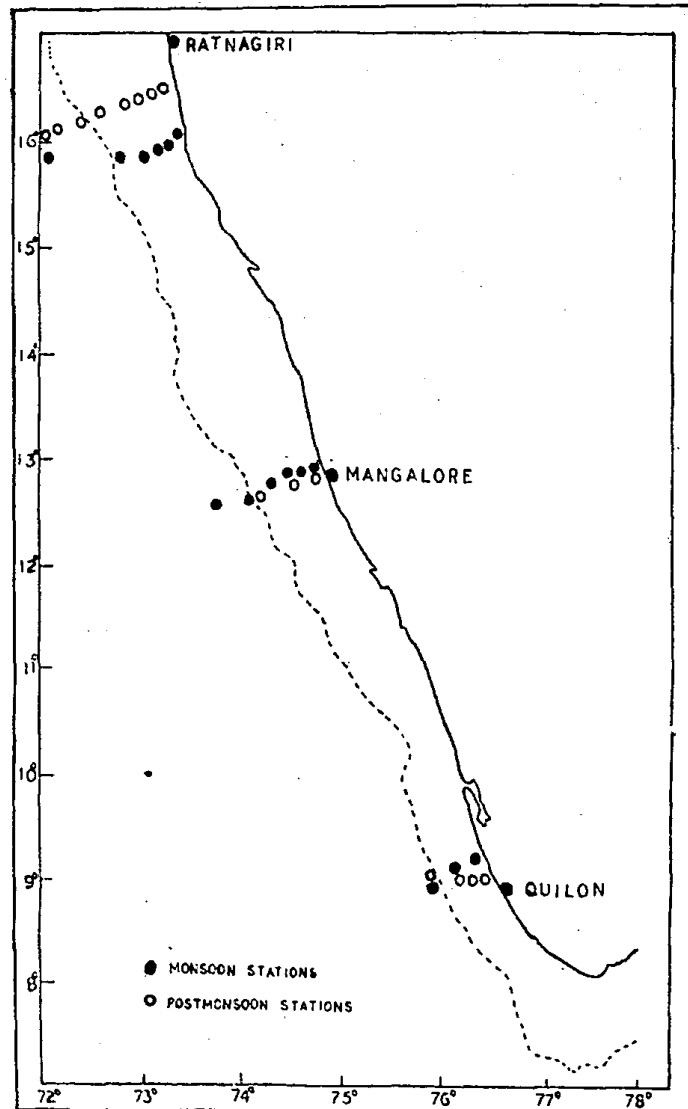


FIG. 1. Map showing the locations wherein collections were made.

and towards the offshore region, it becomes lower ranging from 0.6 to 1.2 $\mu\text{g. at/L}$ (Fig. 2a). In general, throughout the section it is interesting to note that the phosphate concentration dropped from surface to 10 m or 20 m level and the values show a gradual increase up to 50 m, followed by a sharp rise towards the bottom layers; the values reach as high as 2.7 $\mu\text{g. at/L}$. It could be seen from the figure that the isopleths form into a tongue like projection towards the coast suggesting the incursion of offshore waters towards the coast.

Silicate content especially in the inshore stations (Nos. 1914 and 1916; Fig. 2a) shows erratic distribution, but a general trend of increase is evident towards the bottom layers. Farther off, at station No. 1918 near the edge of the continental shelf, the silicate distribution generally parallels with that of phosphate. From the trend of isolines there is also an indication of the influx of offshore waters towards the coast. The values of the upper 10 m varied between 1.7 and 3.1 $\mu\text{g. at/L}$. Bottom layers in the inshore region contain generally more than 5 $\mu\text{g. at/L}$ and reach as high as 14 $\mu\text{g. at/L}$ towards offshore region.

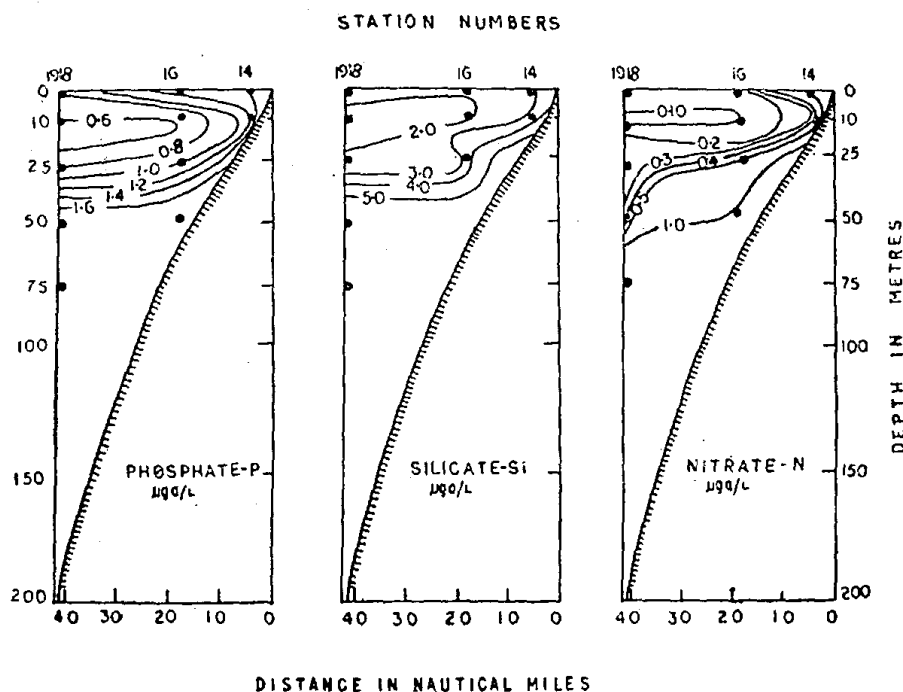


FIG. 2(a) Vertical distribution of phosphates, silicates and nitrates in the section off Quilon in September.

Nitrate distribution is similar to that of phosphate in the upper 10 m. The values tend to decrease towards the offshore region, ranging between 0.1 and 2.8 $\mu\text{g. at/L}$; values greater than 1 $\mu\text{g. at/L}$ are usually found below 20 m and the highest of 4.4 $\mu\text{g. at/L}$ is recorded near the edge of continental shelf at about 100 m. Below this depth the values again tend to decrease to about 1 $\mu\text{g. at/L}$.

Section 'b':—(Along Lat. $9^{\circ}00'$ N between Long. $75^{\circ}58'$ E and $76^{\circ}28'$ E) covered in December 1963. Phosphates in the surface waters remained high (1 $\mu\text{g. at/L}$) in the near shore region and towards the middle of the section they decreased to about 0.4 $\mu\text{g. at/L}$ and thereafter the values tend to increase up to the edge of the shelf reaching 1.8 $\mu\text{g. at/L}$. As compared to the monsoon period the values in the offshore region show an increase. The subsurface isolines (Fig. 2b) show a slight upward tilt from the offshore region towards the mid section and further there is no indication of the upslope of the contours towards the coast.

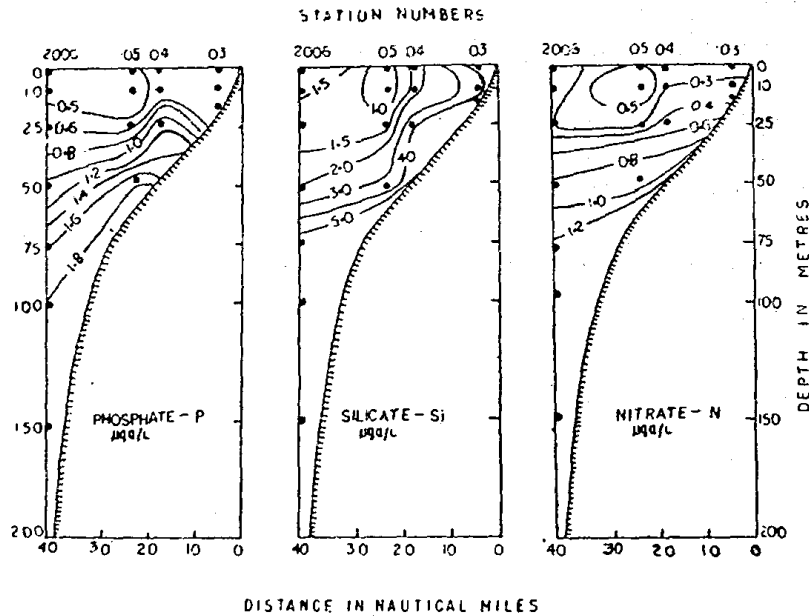


FIG. 2(b) Vertical distribution of phosphates, silicates and nitrates in the section off Quilon in November.

Silicates are generally poor in December relative to the monsoon period, except in the nearshore station No. 2003 wherein a slight increase is noticeable. Surface values varied from 0.73 to 4.8 $\mu\text{g. at/L}$. The values decreased to minimum in the mid region from the coast and thereafter gradually increased towards the shelfedge. Silicate accumulation is significant only below 100 m, the order being 8 to 12 $\mu\text{g. at/L}$.

The trend of nitrate distribution is similar to that of phosphate. Except the first station near the coast, in general, nitrates show a slight increase in the rest of the section. The values ranged from 0.2 to 3.2 $\mu\text{g. at/L}$.

Section Off Mangalore:

Section 'a':—(Between Lat. 12°52' N, Long. 74°54' E and Lat. 12°33' N Long. 73°48' E) covered during October 1963. October represents the month of transition between south-west monsoon is still active, but weak, a gradual reversal of the current system takes place.

Surface phosphates are high (0.8 to 1.5 $\mu\text{g. at/L}$) in the near shore stations within 15 miles and decrease further offshore to below 0.4 $\mu\text{g. at/L}$. The isopleths at the depths between 25 to 50 m (0.5 to 1.5 $\mu\text{g. at/L}$; Fig. 3 a) in the offshore region show a downward trend towards the mid section and again a sharp rise towards the coast reaching the surface. Vertical variation up to about 25 m is not uniform in most of the stations, but there is a sharp increase towards bottom layers below this depth. Values greater than 2 $\mu\text{g. at/L}$ are found below 100 m, particularly in the offshore region.

Silicates also show a trend of distribution similar to phosphates. Surface silicates in the nearshore stations range between 4 and 10 $\mu\text{g. at/L}$, while in the off

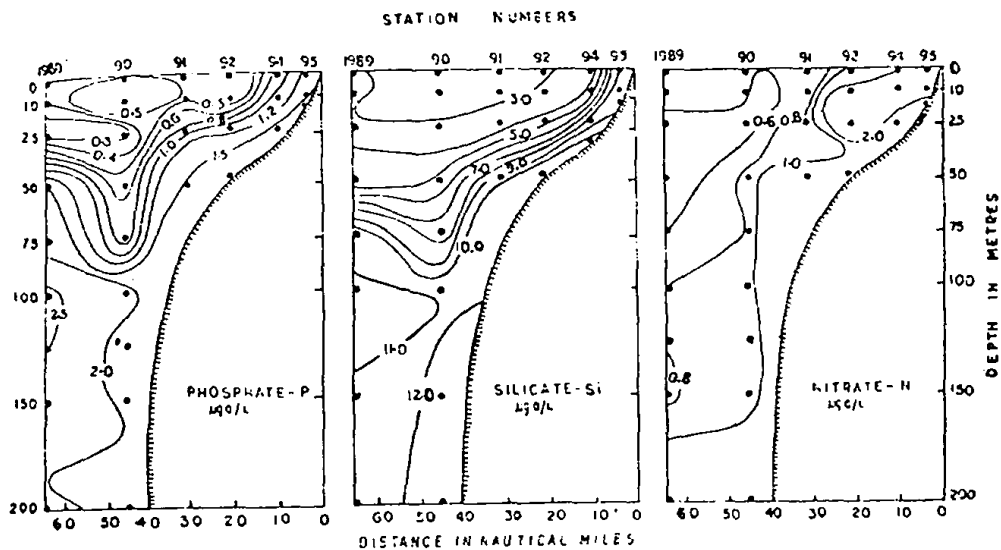


FIG. 3(a) Vertical distribution of phosphates, silicates and nitrates in the section off Mangalore in October.

shore region the values are in general less than 4 $\mu\text{g. at/L}$. Concentrations as high as 12 $\mu\text{g. at/L}$ are found below 100 m.

The pattern of nitrate distribution also shows a strong upslope of the isolines towards the surface near the coast. The values are relatively high in the near shore area, ranging from 1 to 4.5 $\mu\text{g. at/L}$. The concentration is low in the offshore region ranging between 0.4 and 1 $\mu\text{g. at/L}$. Unlike phosphates and silicates, nitrates are generally low down to 150 m. Nitrate accumulation is apparent only below this level.

Section 'b':—(Between Lat. 12°49' N, Long. 74°45' E and Lat. 12°00' N, Long. 72°30' E) covered during the month of December.

In December the phosphate content was very low as compared to October all along the section; the values range from 0.09 to 0.4 $\mu\text{g. at/L}$ (Fig. 3b). This depletion extends up to 100 m and only a slight increase is observed below this level.

Silicates show a similar trend as those of phosphates; the values are between 3 and 5 $\mu\text{g. at/L}$, and higher concentrations ($> 6 \mu\text{g. at/L}$) are found only below 100 m.

Nitrate distribution corresponds more or less to that of phosphates and silicates. Surface values near the coast range from 0.7 to 1.8 $\mu\text{g. at/L}$ and further off the coast the values drop to 0.6 $\mu\text{g. at/L}$. Higher concentrations up to 6 $\mu\text{g. at/L}$ are found below 10 m in the increasing order with depth.

Section off Ratnagiri:

Section 'a':—(Between Lat. 16°03' N, Long. 73°25' E and Lat. 15°50' N, Long. 72°45' E) covered during the month of September.

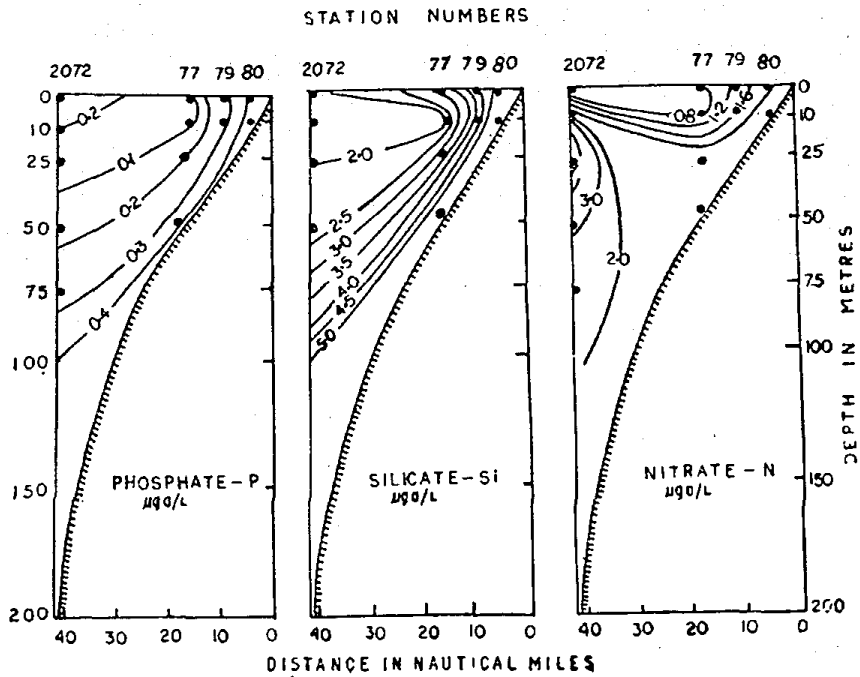


FIG. 3(b) Vertical distribution of phosphates, silicates and nitrates in the section off Mangalore in December.

Surface layers of the inshore area are found to have higher phosphate concentrations (0.8 to 1.3 $\mu\text{g. at/L}$) and lower (0.6 to 0.8 $\mu\text{g. at/L}$) towards offshore. Isoleths (Fig. 4a) between the depths 30 and 75 m in the offshore region show a

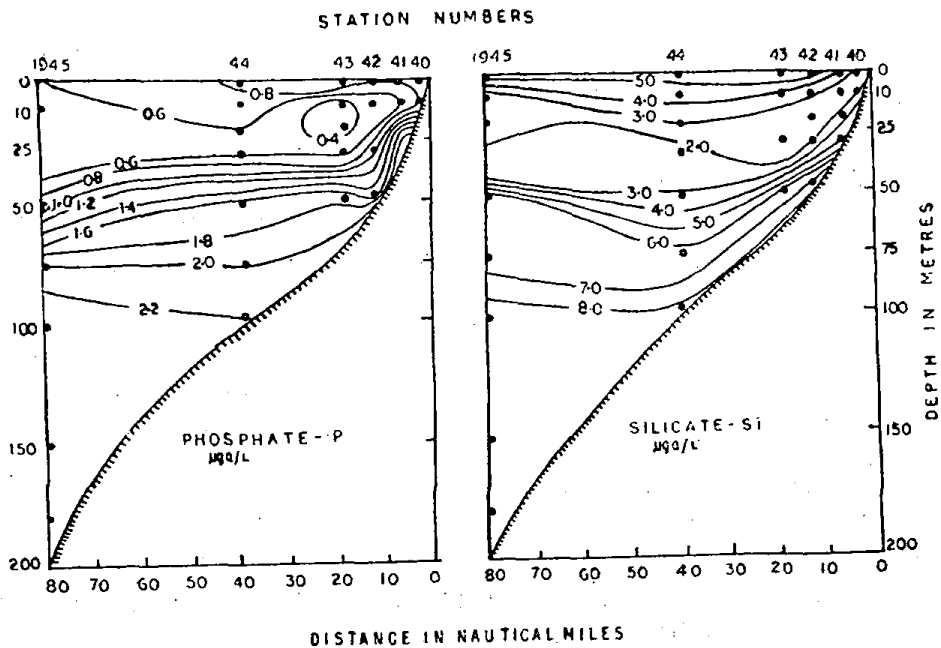


FIG. 4(a) Vertical distribution of phosphates and silicates in the section off Ratnagiri in September.

gradual upslope towards the coast, ascending to levels between 10 and 25 m. In general the concentration is observed to be in decrease from surface to 20 m along the entire section and below this depth, it increases gradually reaching maximum of $2.7 \mu\text{g. at/L}$ near the bottom.

Silicate distribution is quite similar to that of phosphate. Horizontal variation along the section shows that the surface values near the shore are between 2.8 and $9.6 \mu\text{g. at/L}$ and those of offshore between 5.6 and $6 \mu\text{g. at/L}$. Below 40 m there is uniform increase; maximum values up to $12 \mu\text{g. at/L}$ are recorded at the bottom layers near the edge of the shelf.

Section 'b':—(Between Lat. $16^{\circ}28'$ N, Long. $73^{\circ}16'$ E and Lat. $16^{\circ}01'$ N, Long. $71^{\circ}56'$ E) covered during the month of December.

Surface phosphates are in general lower relative to the monsoon period. The values are between 0.2 and $0.6 \mu\text{g. at/L}$. It could be seen from the Fig. 4b that

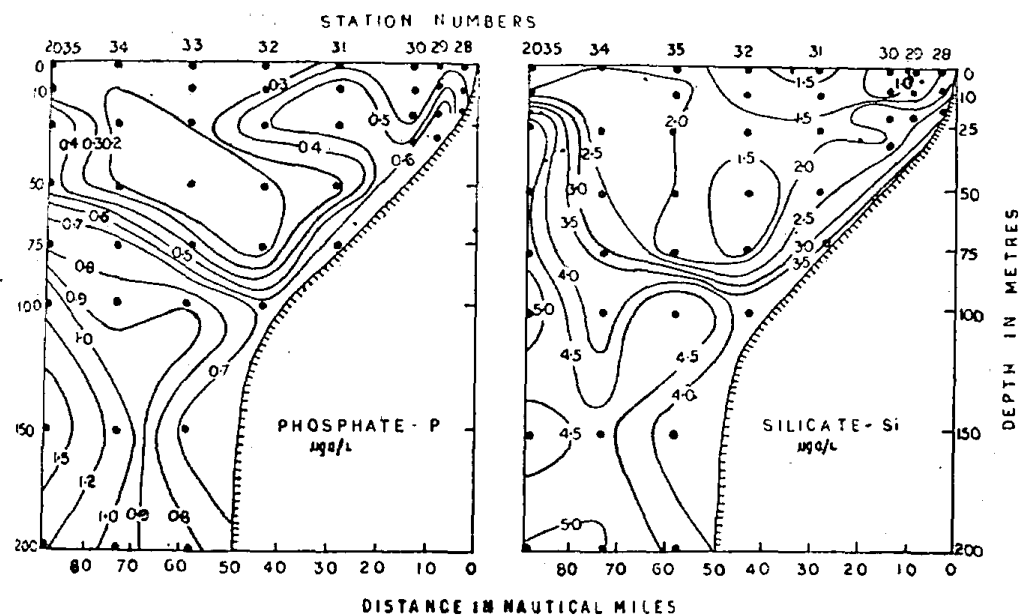


FIG. 4(b) Vertical distribution of phosphates and silicates in the section off Ratnagiri in December.

the isolines between the depths 20 and 95 m of the offshore region show a tendency of down-slope towards the middle of the section, followed by a strong deviation near the coast; the isolines of lower concentrations (0.7 to $0.9 \mu\text{g. at/L}$) shift upwards while those of higher concentrations downward. Concentrations below 100 m are constant at deeper stations up to 200 m.

Silicate distribution in general closely follows that of phosphate. The values are relatively lower than those of monsoon period. Surface silicates range from 0.5 to $2 \mu\text{g. at/L}$ and are in the increasing order towards offshore waters. Vertical variation is not significant either in the inshore region or in the offshore one; the values in the former range from 0.5 to $3.5 \mu\text{g. at/L}$ and in the latter 2 to $5 \mu\text{g. at/L}$.

Hydrographical conditions and their relation to nutrients:

Data of a few stations have been selected to study the general depth wise variation of the hydrographical features (temperature, salinity and oxygen) and their relation to nutrients. This procedure is adopted for all the sections.

Quilon section:

In September the thermocline is at 20 m extending almost to the bottom in the inshore area and in the offshore region it is present at 30 m (Fig. 5). Salinity does not bear any relationship to temperature above the thermocline; below the

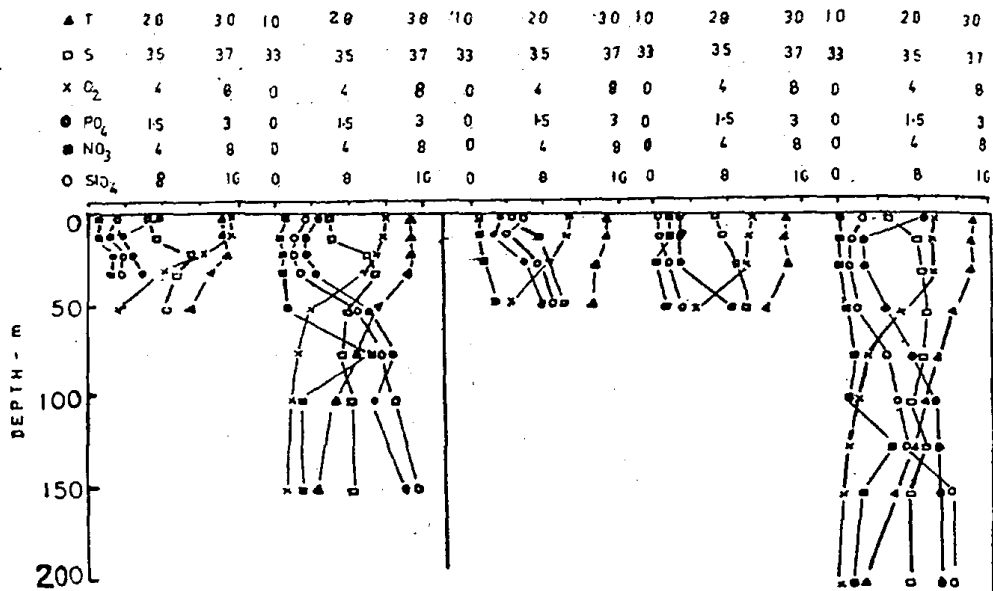


FIG. 5. Depthwise variations of the hydrographical factors and the nutrients at selected stations (Nos. 1916, 1918, 2004, 2005 and 2006) off Quilon in September, and November. Oxygen in ml/litre, nutrients in μg at/litre, salinity in ‰ and temperature in $^{\circ}\text{C}$.

thermocline in the inshore region it shows direct relationship and in the offshore region salinity remains more or less constant. The distribution patterns of phosphates, silicates and nitrates are almost identical above the thermocline, whereas, within the thermocline layer they show some deviation. In the offshore region high values of nutrients are generally associated with low oxygen and low temperatures. Oxygen minimum layer (0.5 and less) is present only near the continental shelf edge at the bottom. Rapid fall in the oxygen concentration is generally noticed just below the thermocline along the entire section. In November the thermocline is absent in the inshore region (within 20 miles) and is present at 25 m in the offshore region extending almost to the bottom and further off, near the shelf edge, it is present at 75 m. The gradient is strong in December as compared to September. Salinity exhibited a general inverse relationship with the temperature. Salinity discontinuity coincides with the thermocline. Nutrients show a good

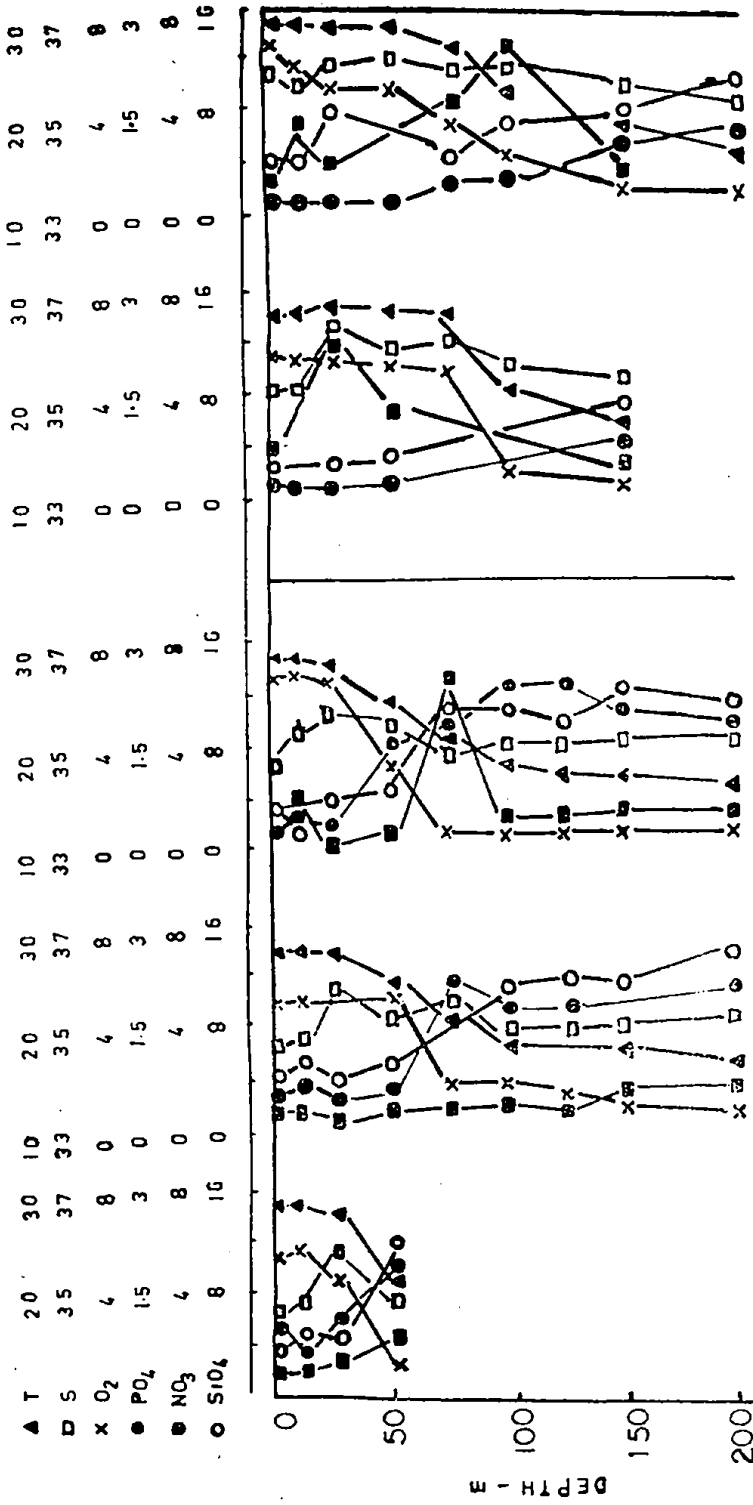


FIG. 6. Depthwise variations of the hydrographical factors and the nutrients at selected stations (Nos. 1989, 1990, 1991, 2077 and 2072) off Mangalore in October and December. Oxygen in ml/litre, nutrients in µg at/litre, salinity in ‰ and temperature in °C.

correlation *inter alia* above and below the thermocline. High nutrient concentrations are associated with lower temperatures and oxygen and higher salinities. Nitrates showed comparatively little variation than phosphates and silicates. Oxygen minimum layer reaches up to the shelf edge, being present at about 160 m. It does not extend over the shelf and the oxygen shows more uniform distribution in contrast to conditions in September.

Off Mangalore:

In October the thermocline in the offshore waters is at 25 m with a thickness of 100 m which slopes gradually towards the inshore region presenting itself at 10 m (Fig. 6). Salinity discontinuity coincides with the thermocline. Waters above the thermocline are more or less isohaline and within the thermocline the salinity variation is irregular and below it is again stable. The top of the oxygen minimum layer which varied between 75 and 145 m in the offshore region showed a strong upslope towards the shelf over which it is present at about 35 m. High nutrient concentrations are as usual accompanied by low temperatures and oxygen, while salinity does not bear any regular relationship with the nutrients.

In December the thermocline in the offshore region, begins at 75 m with thickness extending to 150 m. The spread of the thermocline is limited to the edge of the continental shelf and over the shelf the waters are isothermal. While the temperature pattern shows a fairly good mixed layer above the thermocline, salinity gradients are observed within this layer, sometimes extending down to 100 m. Oxygen minimum layer is present near the edge of the shelf where it is found at about 150 m; over the shelf, the waters are nearly saturated. Phosphate and silicate variations, in general, are consistent with those of temperature, salinity and oxygen. Nitrate concentration, particularly below 25 m, appears to be independent of the hydrographical factors.

Off Ratnagiri:

In September the thermocline is generally present below 30 m with a thickness of 75-150 m in the offshore region, and shows strong upslope towards the coast presenting below 10 m or 20 m, extending down to bottom (Fig. 7). Significantly low salinity ($32-33\text{‰}$) water is present at the surface all along the section excepting in the near shore region, wherein the waters are of higher salinity. Salinity increase is sharp below 10 m reaching maximum at about 30 m and below once again observed to be in decrease. Oxygen minimum layer is present at about 86 m within the thermocline in the offshore waters and in the inshore region it is limited to bottom layers only. Above the thermocline the phosphates and silicates are observed to be decreasing from surface up to the thermocline top and below they show a general increase. Relatively high surface concentrations are associated with the observed low surface salinities. In Sub-surface waters, high nutrient concentrations are generally found to be related with low temperatures and oxygen contents and high salinities.

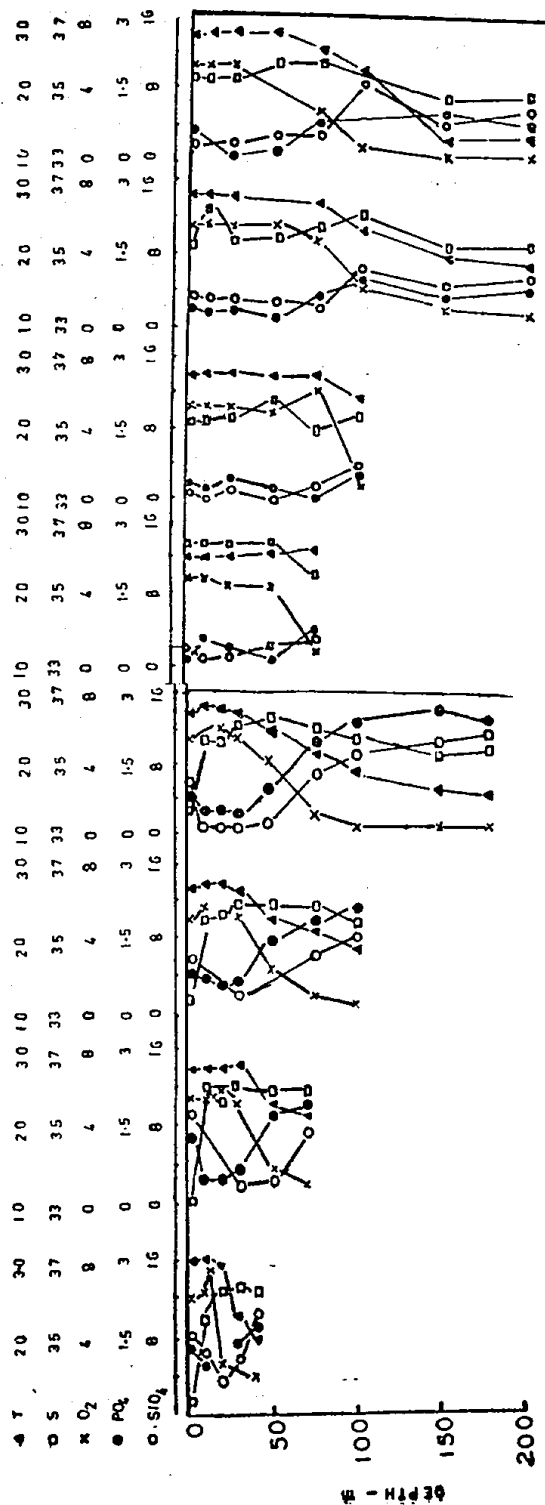


FIG. 7. Depthwise variations of the hydrographical factors and the nutrients at selected stations (Nos. 1942, 1943, 1944, 1945, 2031, 2032, 2033 and 2034) off Ratnagiri in September and December. Oxygen in ml/litre, nutrients in µg at/litre, salinity in ‰, and Temperature in °C.

As compared with the monsoon period, in December the waters are isothermal near the coast and thermocline is present at deeper levels (between 75 and 150 m) towards offshore. In the inshore area waters are more or less isohaline, Salinity discontinuity is significant generally below 25 m in the offshore region and the distribution is irregular. Surface salinity values are relatively higher than in September. Oxygen minimum layer is absent over the shelf region and beyond, it is present at deeper levels (120-185 m). In the near shore waters nutrients showed little vertical variation, which is in conformity with the isothermal and isohaline conditions. Seawards the distribution appears to be independent of the thermocline conditions. However, the accumulation is significant below the thermocline.

DISCUSSION

The present studies at three selected regions across the West Coast covering the shelf waters provide some picture of the distribution of nutrients on the West Coast of India.

The vertical profiles of nutrients during the monsoon months indicate the enrichment of coastal waters by the nutrients brought up from the sub-surface levels. This gives a picture of upwelling which is further corroborated by the distribution of salinity and temperature. Along the south-west coast of India, the presence of a distinct band of water which has all the characteristics of an upwelled water is evident. It is possible that this enrichment could be the result of certain dynamic factors associated with the prevailing southerly drift during the monsoon months. The degree of enrichment may vary from year to year and from region to region and these could be attributed probably to varying intensities of the southerly flow. During the post-monsoon months this phenomenon is absent and the waters are more or less stable. This feature is consistent with the reversal of the current system observed during the period which favours the opposite conditions i.e. sinking (Ramamritham and Jayaraman 1960).

The present nutrient studies suggest that the processes of enrichment are more intense towards southern part of the West Coast of India. The decrease in the concentration of nutrients following the period of enrichment is to be attributed to possible utilization by the phytoplankton. Increased vertical stability of the waters particularly in the post-monsoon period keeps the nutrient levels low. The nutrient concentrations in the near shore region are relatively less affected through different seasons as compared with the major part of the shelf waters. These concentrations are generally very high, possibly due to the rapid regeneration of nutrients by bacterial oxidation and chemical decomposition. The effect of constant mixing of the entire water column due to turbulence prevailing throughout the year is felt more near shallow regions. Further offshore, marked variations in the nutrient levels are observed in different seasons. The observed low nutrient levels in the more offshore regions as compared with the near shore regions might be due to the fact that consumption exceeds regeneration and lack of active replenishment of nutrients; in the nearshore region the converse is true.

Regarding the nutrient relationship *inter alia*, it is noted that at all sections (Figs. 5-7) phosphate and silicate values show similar trends. Nitrates in general show an inverse relationship with the other nutrients particularly in the surface at a slightly deeper level than those of phosphate and silicate. These differences in maxima of respective nutrients might be, as suggested by Redfield *et al.* (1963), due to more rapid release of certain nutrients earlier than others and it provides a mechanism by which nitrogen and phosphorus may be fractionated and this may explain the variation in the ratio of these elements in the sea water. The ratio between elements Si, N, and P as observed in the present context, is highly variable unlike that of the temperate region. This variation may presumably be due to the differential and rapid rates of regeneration and consumption of the nutrients accompanied by extensive mixing of water masses which seems a characteristic feature of tropical waters.

Hydrographical features like temperature, salinity and dissolved oxygen also lend support to some of the conclusions drawn from the distribution of the various nutrients. A brief mention of these features during the period of investigation and their relationship with nutrients would be pertinent for the present discussion.

Thermocline is rather weak during the monsoon months and strong during the post-monsoon months. The nutrients are present in very high concentrations below the thermocline. The steep temperature gradient in the post-monsoon months, prevents the vertical mixing of the waters and thus hinders the replenishment of the nutrients to the upper layers. Salinity unlike temperature and oxygen does not bear marked relationship with nutrients. It is noted from the salinity and nutrient data off Quilon and Ratnagiri sections in September, that the effect of land drainage is not very significant. This is unlike in the East Coast of India where many large rivers flow into the Bay of Bengal. One of the significant points in the hydrographical features, is that the surface salinities in the more northern Ratnagiri section are somewhat lower than those in the more southern Mangalore and Quilon sections in September. This gives some evidence of a greater intensity of upwelling in the southern part of the West Coast. Another important feature worth mentioning particularly in the deeper parts of the shelf is that during monsoon months, a distinct salinity maximum is noted between 20 and 30 meters and in the post-monsoon months between 50 and 100 meters and these layers are seen just above or to coincide with the depth of oxygen discontinuity layer. Nutrients, especially phosphates and silicates show a rather abrupt increase at this depth and below. This layer of salinity maximum probably has its source in the offshore region, but during the monsoon months influences the salinity of the near shore region. Oxygen discontinuity shows the same trend of variations as thermocline through the different seasons. The low oxygen values and the associated high nutrients at these levels are indicative of active regenerative process leading to consumption of oxygen with ultimate concentrations reaching as low as 0.5 ml/L.

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REFERENCES

- Admiralty. (1960) West Coast of India Pilot, London.
- Banse, K. (1959). On upwelling and bottom trawling off the southwest coast of India. *J. mar. biol. Ass. India*, **1**, 33-49.
- Barnes, H. (1960). Apparatus and Methods of Oceanography. Part I, Chemical, London.
- Broenkow, W.W. (1965). The distribution of nutrients in the Costa Rica Dome in the Eastern Tropical Pacific Ocean. *Limnol. Oceanogr.*, **10**, 40-52.
- 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.
- Jayaraman, R., and Seshappa, G. (1957). Phosphorus cycle in the sea with particular reference to tropical inshore waters. *Proc. Indian Acad. Sci.*, **46**, 110-125.
- Panikkar, N.K., and Jayaraman, R. (1956). Some aspects of productivity in relation to fisheries of Indian neritic waters. *Oceanography & Zoology. Proc. 8th Pacific. Sci. Congr.*, **34**, 1111-1122.
- Ramamritham, C.P., and Jayaraman, R. (1960). Hydrographical features of the continental shelf waters off Cochin during the years 1958 and 1959. *J. mar. biol. Ass. India*, **11**, 199-207.
- Redfield, A.C., Ketchum, B.H., and Richards, F.A. (1963). The influence of organisms on the composition of seawater. *The Sea*, **2**, 26-77.
- (1958). Dissolved silicates and related properties of some western North Atlantic and Caribbean Waters. *J. mar. Res.*, **17**.
- Richards, F.A. (1960). Some chemical and hydrographic observations along the north coast of South America. *Deep Sea Res.*, **7**, 163-182.
- Robinson, R.J., and Thompson, T.G. (1948). The determination of silicates in sea water. *J. mar. Res.*, **7**, 49-55.
- Ryther, J.H. (1963). Geographic variations in productivity. *The Sea*, **2**, 347-380.
- Sastry, A.A.R., and Myrland, P. (1960). Distribution of temperature, salinity and density in the Arabian Sea along the south Kerala Coast (S. India) during the post-monsoon season. *Indian J. Fish.*, **6**, 223-255.
- Seshappa, G., and Jayaraman, R. (1956). Observations on the composition of bottom muds in relation to the phosphate cycle in inshore waters of the Malabar Coast. *Proc. Indian Acad. Sci.*, **43**, 288-301.
- Subrahmanyam, R. (1959). Studies on the phytoplankton of the West Coast of India. Part I. *Proc. Indian Acad. Sci.*, **50B**, 113-187.
- (1959). Studies on the phytoplankton of the West Coast of India. Part II. *Proc. Indian Acad. Sci.*, **50B**, 189-252.
- Suryanarayana Rao, S.V. (1957). Preliminary observations on the total phosphorus content of the inshore waters of the Malabar Coast off Calicut. *Proc. Indian Acad. Sci.*, **45B**, 77-85.
- Sverdrup, H.U., Johnson, M.W., and Fleming, R.H. (1942). *The Oceans, Their Physics, Chemistry and Biology*. New York.
- Vinogradov, M., and Voronina, N.H. (1960). Influence of the oxygen deficit on the distribution of plankton in the Arabian Sea. *Deep Sea Res.*, **9**, 523-530.
- Wooster, W.S., and Rakestraw, N.W. (1951). The estimation of dissolved phosphates in sea water. *J. mar. Res.*, **49-55**.