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PLANKTON PRODUCTION ASSOCIATED WITH COLD WATER INCURSION INTO THE ESTUARINE ENVIRONMENT

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ABSTRACT

Phytoplankton blooms comprising mainly of diatoms and dinoflagellates ($\sim$ 0.55 million cell/l) and intense zooplankton swarms (biomass $\sim$ 5.34 ml/m^3) were observed in the Mandovi and Zuari estuarine environment in October-November 1980. During this period, pigment concentrations varied from 1.0 to 10.2 mg/m^3.

Temperature, dissolved oxygen and salinity at the upper layers showed variations from 26.77 to 30.15°C, 4.7 to 5.8 ml/l and 27.25 to 34.4‰ respectively. The nutrients such as NO_2-N (0.35–1.4 µg at/l) and PO_4–P (1.4–2.8 µg at/l) were high, whereas NO_3–N was low (0.23–0.92 µg at/l). At the subsurface layers temperature, dissolved oxygen and salinity varied from 22.5 to 29.16°C, 0.6 to 56 ml/l and 32.7‰ respectively. The variation of NO_3–N was from 0.23 to 1.15 µg at/l, NO_2–N from 0.37 to 3.34 µg at/l and PO_4–P from 1.43 to 4.45 µg at/l.

The incursion of cold, nutrient-rich subsurface waters into the euphotic region augmented the plankton production of the Mandovi and Zuari estuarine environment.

Key-words : Plankton, blooms, estuary.

INTRODUCTION

The coastal and nearshore waters of the west coast of India are enriched by heavy rainfall and land runoff from June to September every year. During this period the effect of upwelling is fairly wide spread along this coast and adds to further enrichment of the aquatic environment. Sankaranarayanan, Rao and Antony (1978) observed upwelled waters occurring in the coastal waters of Goa during August–October. The occurrence of red tide phenomenon was reported to be another source of enrichment to the marine environment during February–May (Devassy, Bhattathiri and Qasim, 1978; Qasim, 1970). During the course of investigations on primary production in these waters cold water mass rich in nutrients with low dissolved oxygen were observed in the subsurface waters of the Mandovi and Zuari estuarine environment during October-November. This feature together with the phytoplankton blooms and zooplankton swarms observed are discussed in relation to the environmental features.

MATERIALS AND METHODS

The parameters such as temperature, salinity, dissolved oxygen, inorganic NO_3–N, NO_2–N, PO_4–P; primary production, chlorophyll *a*, particulate organic carbon (POC) and phytoplankton cell counts have been investi-

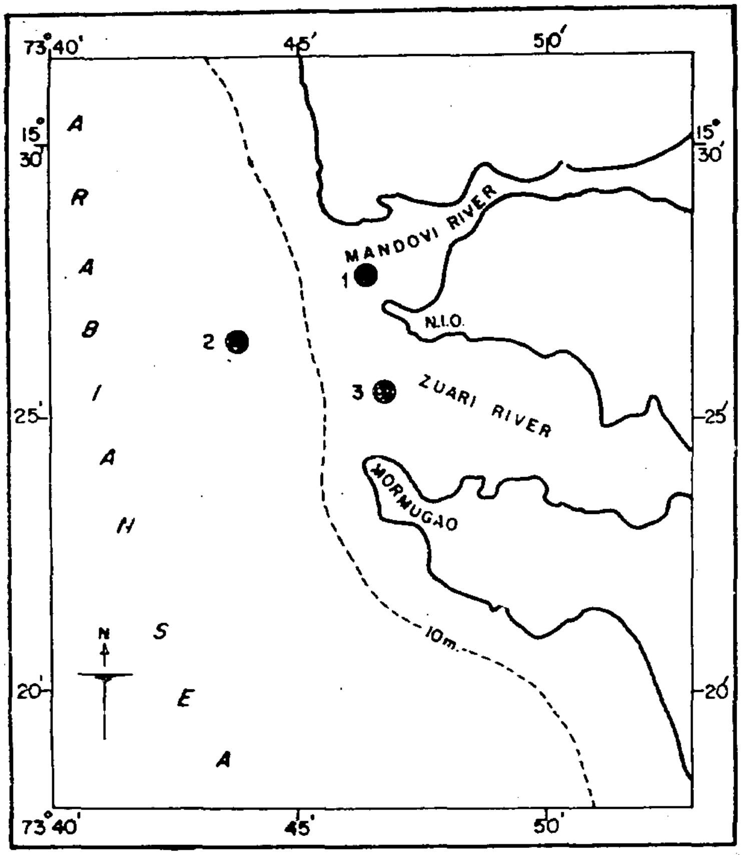

Fig. 1. Location of sampling stations.

gated from 7 October 1980 to 12 November 1980 at 3 stations (Fig. 1). Chemical analyses were done following Strickland and Parsons (1968); chl *a* by fluorometry (corrected for phaeophytin) and POC by wet acid digestion. ^{14}C samples were incubated for 4-5 hrs (between 1000 and 1500 hrs). ^{14}C incubated samples were filtered through membrane filters of 0.45 μm pore size. The filters were exposed to acid fumes, dried and then counting effected in a Liquid Scintillation System (ECIL) by channel ratio method. ^{14}C uptake was calculated after correcting for dark uptake. Horizontal surface zooplankton hauls of 5 minutes duration were taken with an HT net (0.22 mm mesh width) with a flowmeter attached. In the following text usage of surface, mid-depth and bottom indicate the depths of 100, 30 and 1% incident light respectively.

RESULTS AND DISCUSSION

Temperature : Wide fluctuations in temperature were noticed. While temperature in the area fluctuated from 26.77 to 30.15°C at the surface (Fig. 2), the variation at the subsurface was from 22.5 to 29.16°C. Tempera-

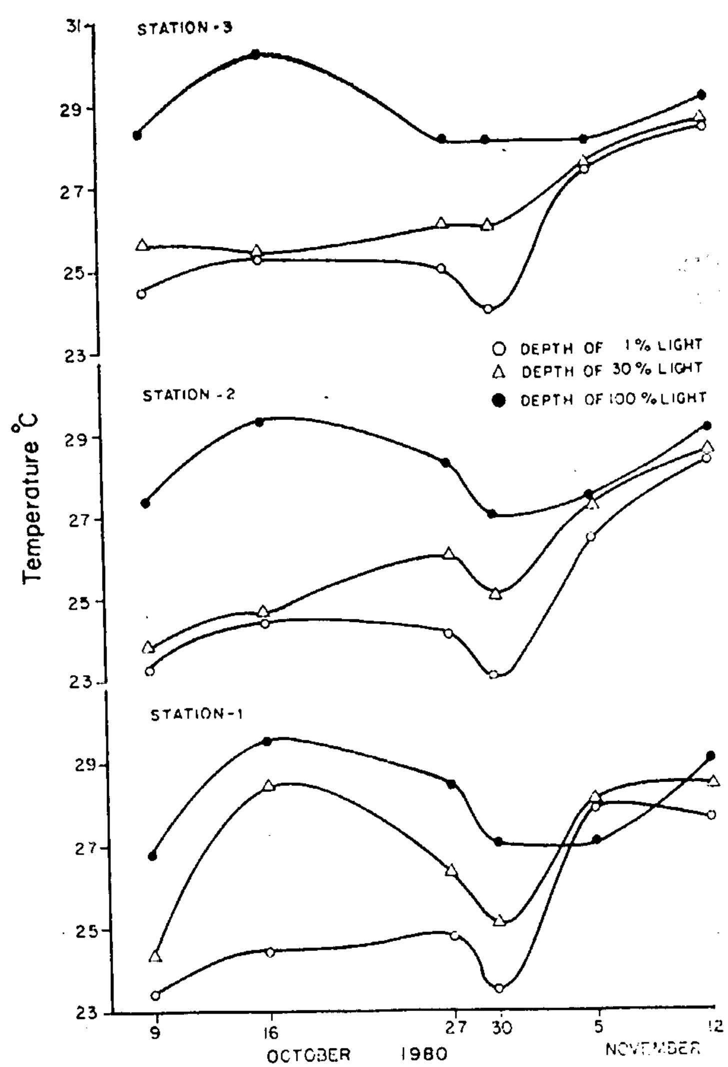

Fig. 2. Depthwise variations in temperature.

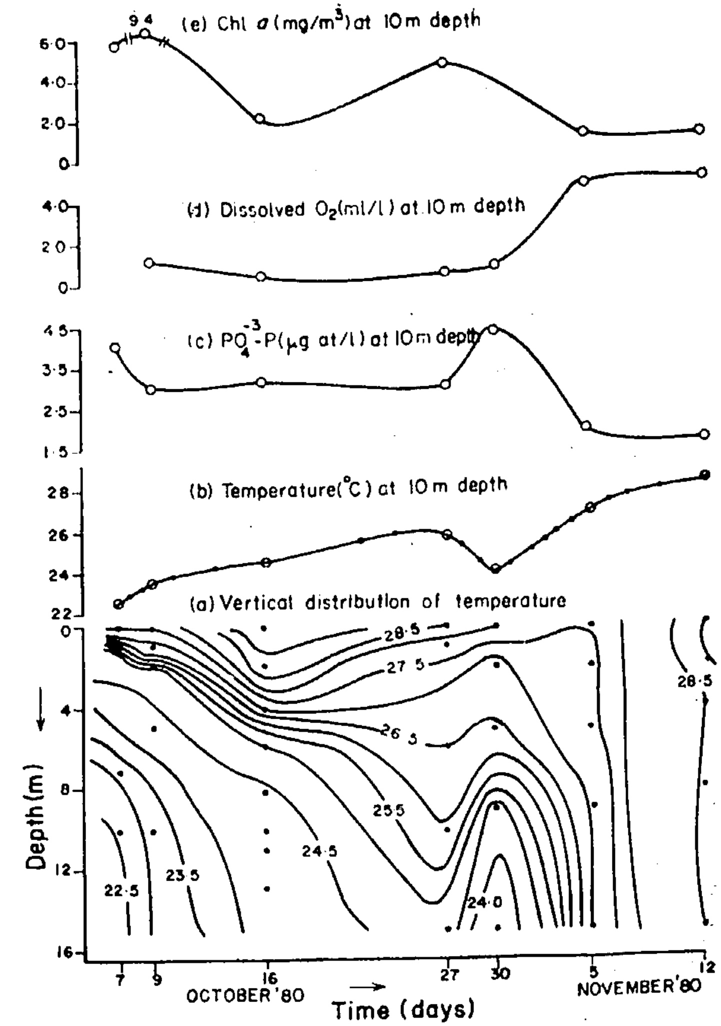

Fig. 3. Station 2: (a) Temperature (°C) distribution with time, (b) Temperature (°C) at 10 m depth, (c) PO_4^{-3}-P (μ g at/l) at 10 m depth, (d) Dissolved O_2 (ml/l) at 10 m depth and (e) Chl a (mg/m^3) at 10 m depth.

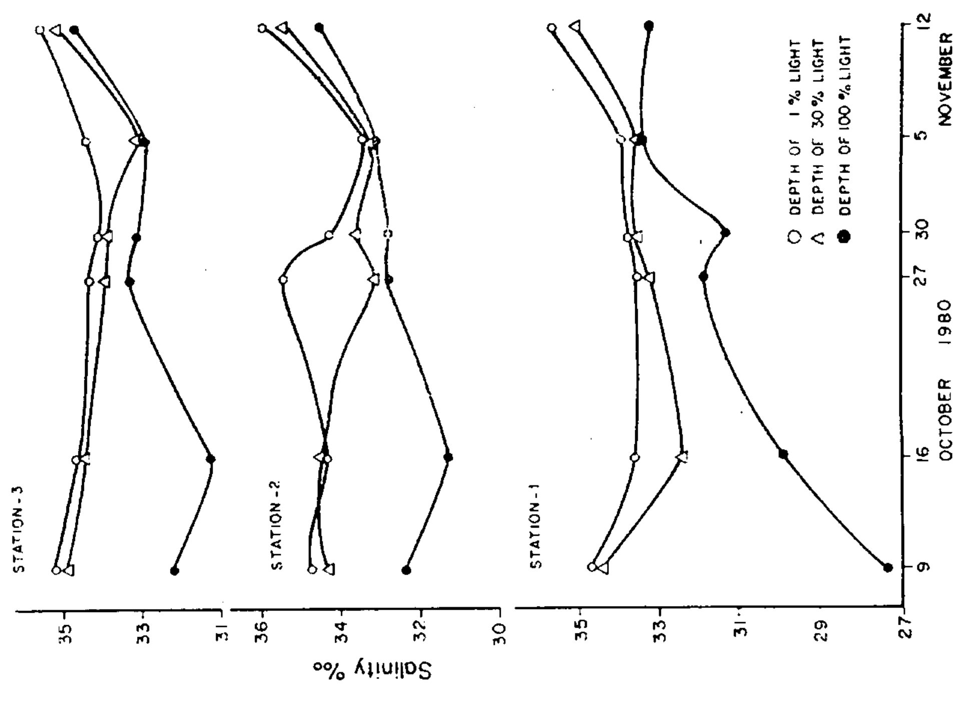

Fig. 4. Depthwise variations in salinity.

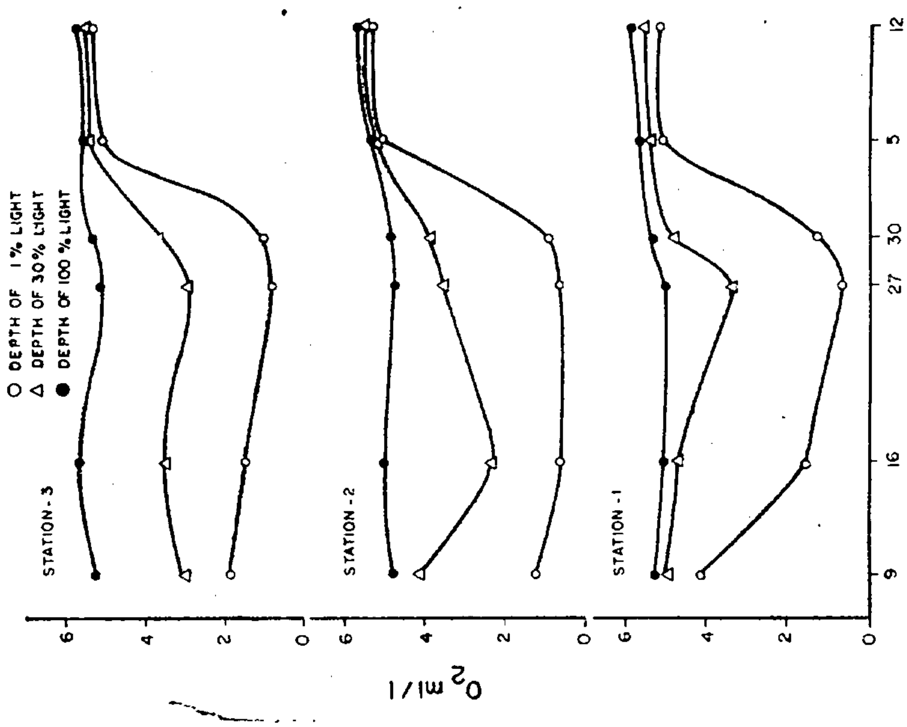

Fig. 5. Depthwise variations in dissolved oxygen.

ture variation was much more pronounced at station 2 than at the other two stations. Strong thermal gradients prevailed in the upper 1 m column during the first half of October. Subsequently the thickness of this layer increased to nearly 6 m in about ten days. Towards the end of October, the water column indicated presence of cold water (23.85°C) of nearly 6 m thickness close to the bottom. The cold water dome could be clearly seen from Fig. 3a. From early November onwards the conditions were more close to isothermal nature with water temperature increasing with time.

Salinity: Salinity values were lower at the surface and higher at the subsurface (Fig. 4). At station 1, salinity fluctuated from 27.25 to 34.25‰, at the surface and from 33.4 to 35.8‰ at the bottom showing considerable amount of dilution at the surface layers. At station 2 it varied from 31.2 to 34.4‰ at the surface and from 33.0 to 35.4‰ at the bottom. Salinity ranges were 31.3 to 34.4‰ and 34.7 to 35.4‰ at the surface and bottom respectively at station 3.

Dissolved oxygen : Dissolved O_2, in general, was low till the end of October and increased thereafter at the 3 stations (Figs. 3d and 5). At station 1, it fluctuated from 0.8 to 5.7 ml/l, at station 2 from 0.6 to 5.6 ml/l and at station 3 from 0.8 to 5.6 ml/l from near-bottom to surface respectively. Surface oxygen concentration never dropped below 4.7 ml/l during the period.

Nutrients: Fig. 6 shows the variations in NO_3-N concentrations which fluctuated from 0.35 to 1.4 μg at/l in the water column at station 1, the higher concentrations being at the bottom. At station 2, higher values were obtained at the bottom, the maximum being 3.34 μg at/l. At station 3 also higher values were observed at the bottom. NO_2-N concentrations (0.23 to 0.93 μg at/l) were lower than those of NO_3-N. Relatively higher concentrations were recorded on 27 October at station 1 and 2 (Fig. 7).

PO_4-P values varied from 1.4 to 4.45 μg at/l in the area. While high concentrations were recorded at the mid depth and bottom, surface values were always low (Fig. 8). The near-bottom PO_4-P concentrations at station 2 were higher than the other two stations till 30 October. Lowest values were observed on 12 November at all stations.

Phytoplankton : Standing crop was higher at near-bottom on 9 and 16 October at station 3, on 9 October at station 2 and on 16 October at station 1 (Fig. 9). Phytoplankton at the surface showed a peak in late October at all stations. The highest density was observed on 30 October at station 2 in the surface layers ($\backsim$ 0.55 million cell/l).

Diatoms generally dominated the phytoplankton population though dinoflagellates surpassed them on two occasions. In early October diatom population was high at the surface at station 1 although it declined on 16 October. On 27 and 30 October again the diatoms recorded an increase ($>$ 0.13 million cell/l) at the surface at all stations and thereafter. The popu-

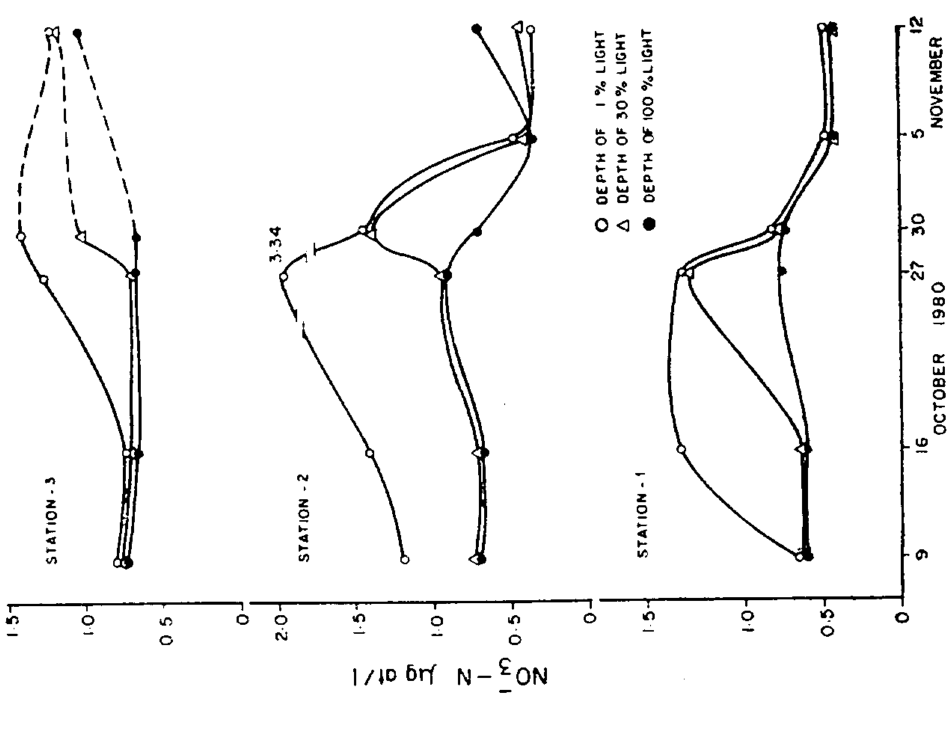

Fig. 6. Depthwise variations in NO_3-N.

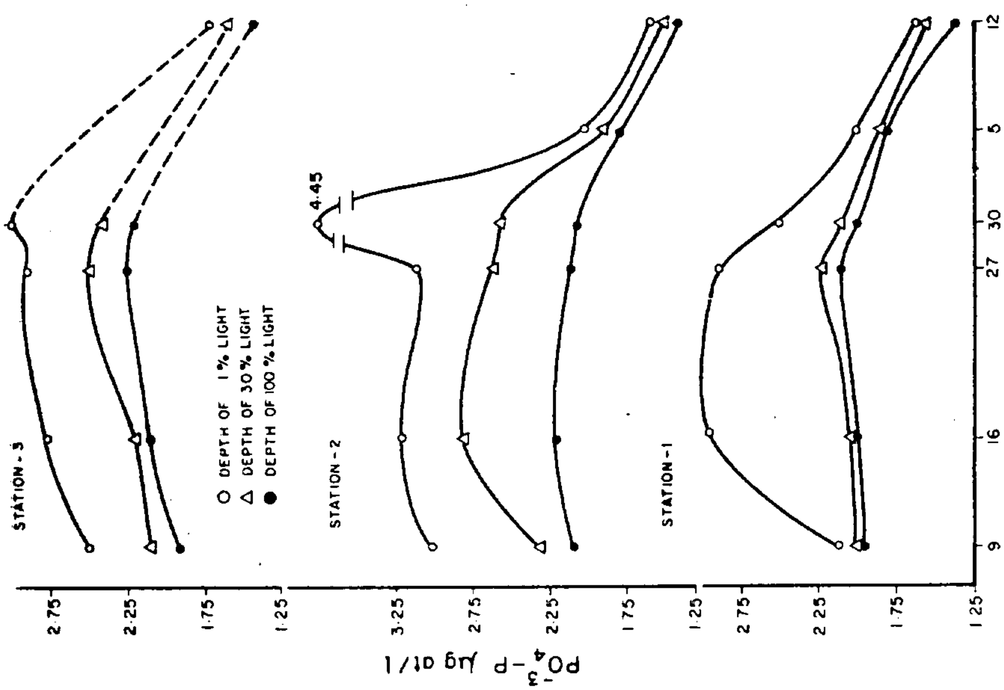

Fig. 8. Depthwise variations of PO_4^{-3}-P.

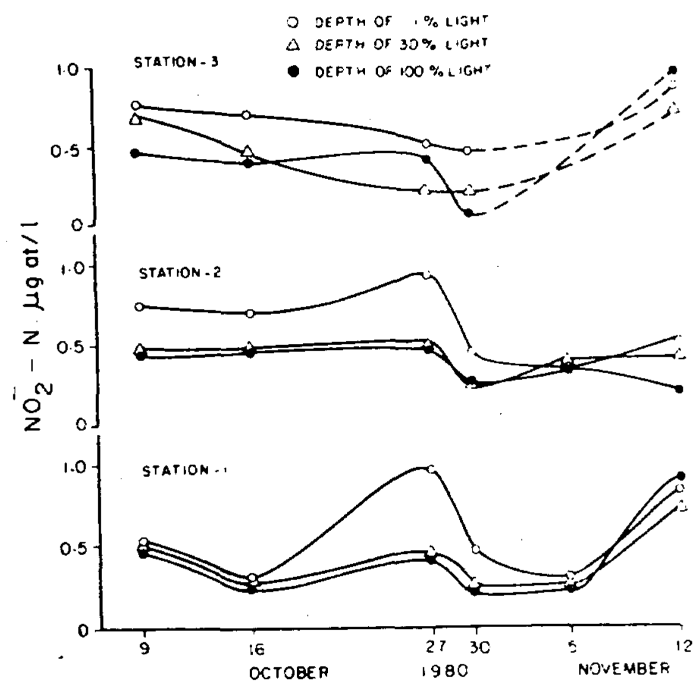

Fig. 7. Depthwise variations in NO_2 -N.

lation declined considerably. Bottom population at station 2 was high on 9 October, though there was a decline on 16 October. From then onwards an increasing trend in diatoms could be discerned till 30 October and thereafter the population decreased again (Fig. 10).

During the present investigation 49 species of diatoms belonging to 33 genera were recorded. The predominant forms were species of Coscinodiscus, Chaetoceros, Leptocylindrus, Navicula, Nitzschia, Pleurosigma, Rhizosolenia and Skeletonema.

Dinoflagellates contributed 72.2% of the total phytoplankton at the bottom at station 1 (Fig. 11). At stations 2 and 3 dinoflagellate population was high at the surface on 30 October. There were 17 species of dinoflagellates belonging to 8 genera. The dominant forms were species of Gonyaulax, Peridinium, Exuviella and Prorocentrum.

Chlorophyll a : Pigment concentrations showed a fluctuating trend similar to that of phytoplankton. At station 1 surface chl *a* was high on 9, 27 and 30 October. At station 2 the highest concentration was noticed at near-bottom on 9 October (Fig. 12) and subsequently there was a decline on 16 October at all depths and again an increase on 27 and 30 October. Station 3 showed the highest chl *a* concentration of 10.2 mg/m^3 at the surface on 27 October.

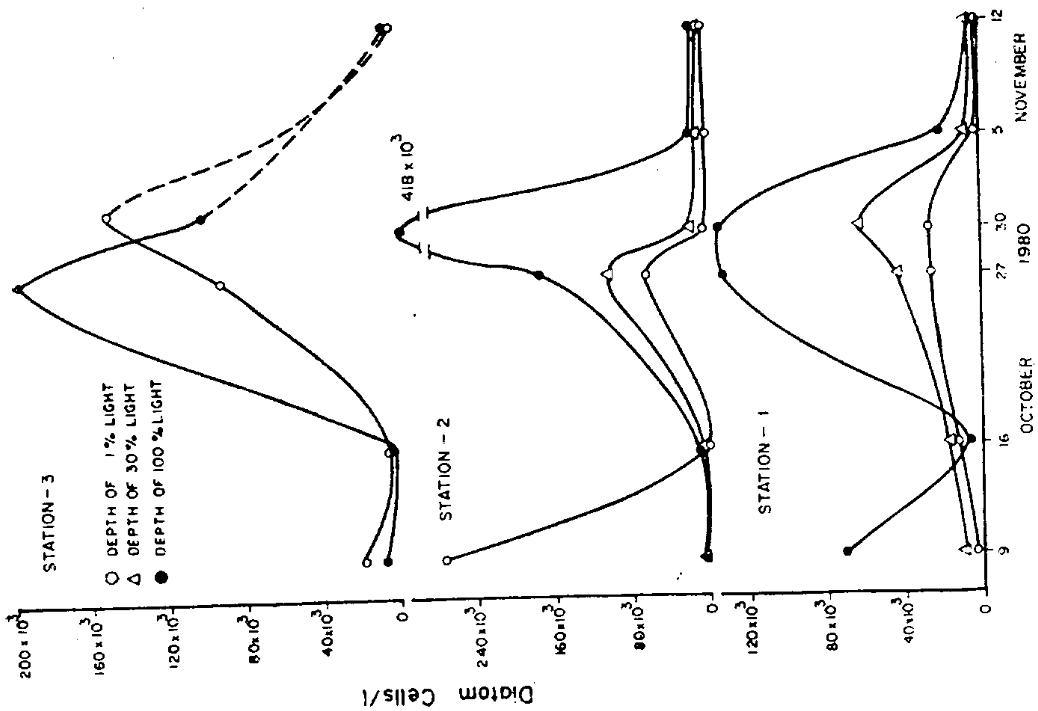

Fig. 10. Depthwise distribution of diatoms.

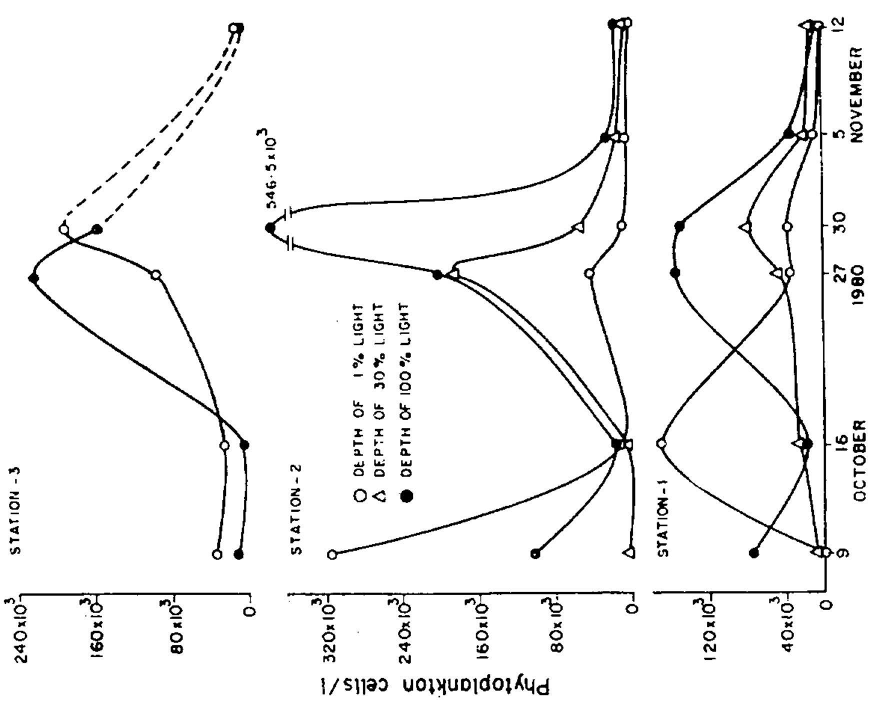

Fig. 9. Depthwise distribution of phytoplankton.

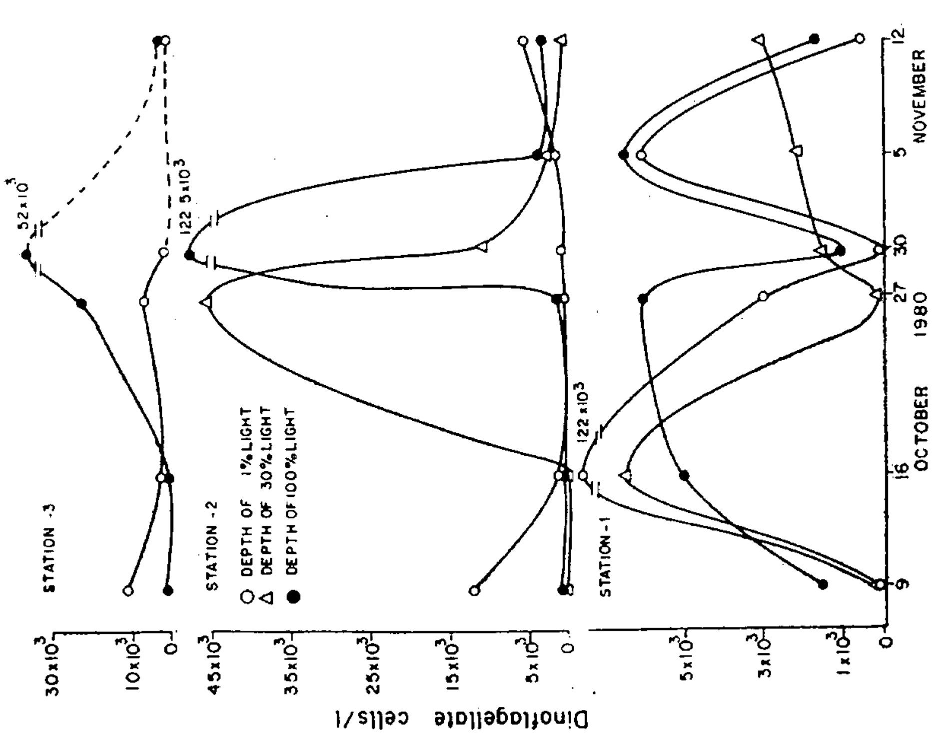

Fig. 11. Depthwise distribution of dinoflagellates.

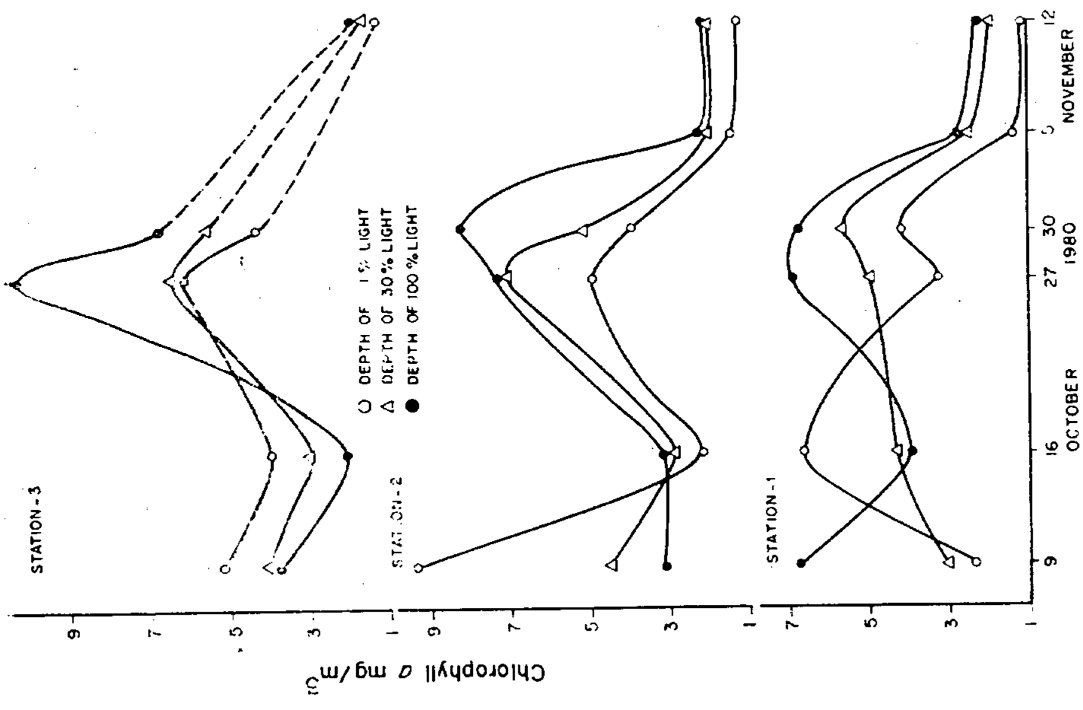

Fig. 12. Depthwise distribution of Chl a.

^{14}C Assimilation and particulate organic carbon (POC): These were measured only at station 2 (Figs. 13 and 14). Highest values were observed on 27 October at discrete depths and column. The POC concentrations were higher on 9, 27 and 30 October.

Zooplankton: The cladoceran *Evadne tergestina* predominated the zooplankton surface population on 9 October. The entire region had a speckled appearance on 16 October which was evidently due to a heavy population of *Creseis acicula*. On this date a record high biomass of 5.34 ml/m^3 was observed at station 1 (Fig. 15). Numerically *C. acicula* alone contributed 99.37% (58758 no/m^3) and 98.21% (39490 no/m^3) of the total population at stations 1 and 2 respectively. Earlier, Sakthivel and Haridas (1974) recorded off Cochin, a swarm of *Creseis acicula*, synchronising with a swarm of *Penilia avirostris* at the time of a *Trichodesmium* bloom. On 27 October copepods dominated at different locations, followed by chaetognaths, fish eggs, decapod larvae and Lucifer sp. Fish eggs, copepods, cladocerans and chaetognaths dominated the zooplankton on 30 October. On the whole zooplankton population declined from 27 October onwards at various locations.

Significance of the cold water plume: A close examination of temperature and salinity at station 2 showed the presence of strong stratification during the first half of October. Later the cold water lost its identity and well mixed conditions prevailed from first week of November onwards (Fig. 3). October, being a month of transition from the point of meteorological parameters, the observed conditions in the water column also have been found to reflect similar transition features.

Sankaranarayanan, Rao and Antony (1978) observed low temperature and low oxygen and high PO_4–P values prevailing in the subsurface waters at the lower reaches of the Mandovi and Zuari estuaries and the nearshore waters during August-October. They observed low temperature of 21.1°C at the depth of 23 m. They also observed low surface temperature of the order of 24°C in the nearshore waters. In the present investigations, the surface temperature varied between 27.0 and 29.5°C. However, this feature largely depends on the time of observation. Sankaranarayanan, Rao and Antony (1978) recorded PO_4–P concentration of 5.89 μg at/l coupled with low temperature and dissolved oxygen. Demersal fishes and prawns were also caught in purse seine during this period. They attributed this incidence to low temperature and oxygen content at the bottom causing asphyxiation forcing these epibenthic animals to migrate to the surface layers.

Sankaranarayanan and Jayaraman (1972) claimed the intrusion of cold water into the Mandovi and Zuari estuaries during this season. They recorded surface oxygen concentrations varying from 2.4 to 3.88 ml/l and the bottom value as low as 0.23 ml/l in this area.

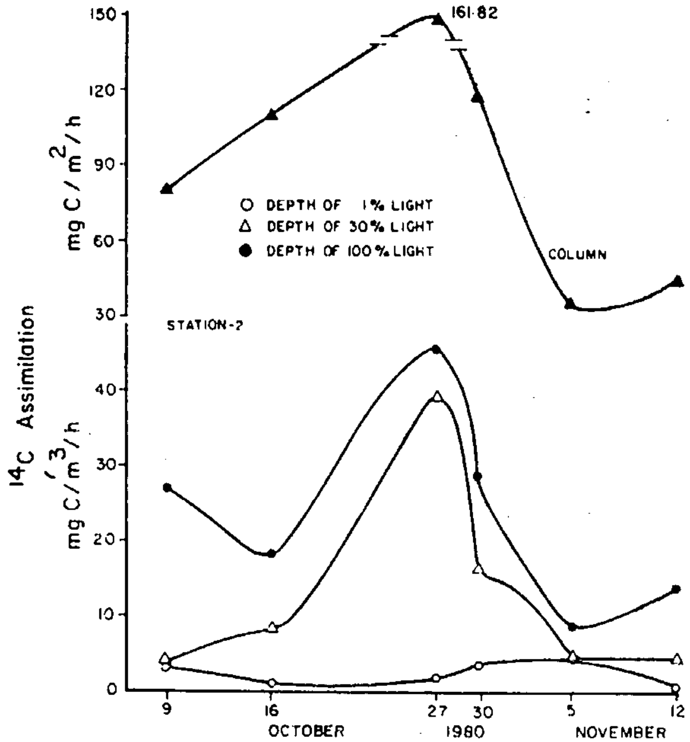

Fig. 13. Variations in depthwise and column carbon production at station 2.

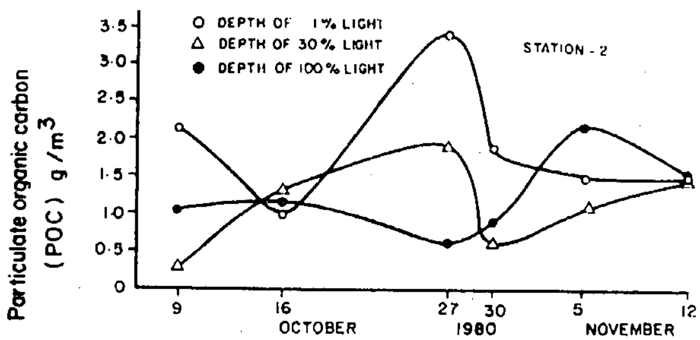

Fig. 14. Depthwise variations in particulate organic carbon at station 2.

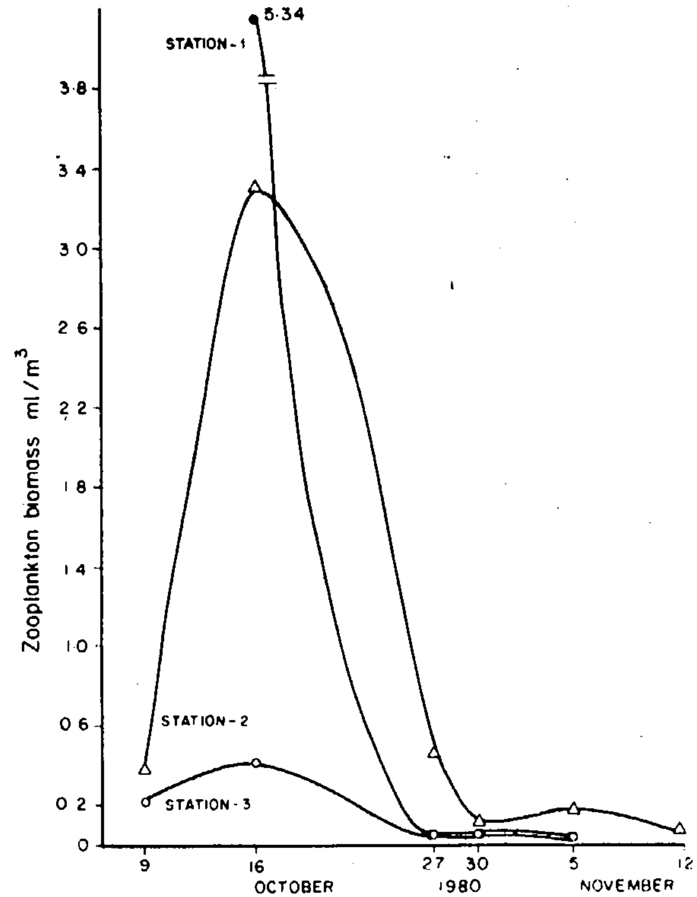

Fig. 15. Distribution of zooplankton biomass.

Further, the occurrence of microscale cold water plume rich in nutrients and chl *a* concentration in the Sagami Bay and adjacent waters around Izu islands (Japan) have been reported by Takahashi, Iioike, Ishimaru, Saino, Furuya, Fujita, Hatton and Ichimura (1980). Beers, Stevenson, Eppley and Brooks (1971) working in the Peru upwelling region, observed high nutrient and pigment concentrations and low temperatures. Similarly chl *a* concentration was found to be relatively high in the Mandovi and Zuari estuarine region.

During the present investigation nutrient levels, in general, were higher than at other seasons and dissolved oxygen lower in the subsurface layers. Ryther, Hall, Pease, Bakun and Jones (1966) working in the western Indian Ocean observed that the levels of nutrients and oxygen, which are inversely related, depend to a large extent upon the speed of circulation and when the latter is particularly sluggish, the subsurface waters may approach or reach complete anoxia. The water samples collected from near-bottom on 27 and 30 October imparted strong hydrogen sulphide smell at all the 3 stations and oxygen concentrations were low at near-bottom during this period.

The significant feature of the present study has been abundance of phytoplankton especially diatoms such as *Chaetoceros* spp., *Fragilaria oceanica* and *Leptocylindrus danicus* attaining bloom proportions. The fluctuating trend of phytoplankton and chl *a* (Fig. 12) in the euphotic column observed during the later part of October could be due to increased productions. On certain occasions even epibenthic forms such as Cumacea and Mysidacea were caught in the surface zooplankton hauls. During the initial stages of the study phytoplankton was found to be more abundant at the compensation depth than at the surface. The abundance of filter feeders like *Evadne tergestina* in the upper layers on 9 October would have been responsible in keeping a check over the population explosion of phytoplankton. However, zooplankton density declined from 27 October onwards and perhaps due to this reason high phytoplankton was prevailing during the period. A high grazing pressure exhibited by the pelagic animal populations would have been the cause for the low standing crops in the nutrient-rich patches with active phytoplankton populations (Strickland Eppley and Rojas De Mendiola, 1969).

The abundant occurrence of phytoplankton and zooplankton population was possibly due to the enrichment caused by the above mentioned transient features. Thus it is concluded the occurrence of nutrient-rich cold water and its subsequent incursion into the euphotic region has enhanced plankton production in the Mandovi and Zuari estuarine environment.

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