# PHYSICAL CHARACTERISTICS OF THE COASTAL WATERS OFF THE SOUTH-WEST COAST OF INDIA WITH AN ATTEMPT TO STUDY THE POSSIBLE RELATIONSHIP WITH SARDINE, MACKEREL AND ANCHOVY FISHERIES

THESIS SUBMITTED FOR THE

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BY

V. NARAYANA PILLAI, M. Sc.

1982

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1982

# DECLARATION

I hereby declare that the work described in this thesis has been carried out entirely by me in the UNDP/FAO Pelagic Fishery Project, Cochin during the period 1977-1979 and further that it has not been submitted either wholly or in part by me to any University or Institution for the award of any Degree or Diploma.

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# C E R T I F I C A T E

I hereby certify that this thesis is a bonafide record of work of Shri.V.Narayana Pillai, M.Sc., carried out by him under my supervision in the UNDP/FAO Pelagic Fishery Project, Cochin and that no part thereof has been presented for any other Degree.

A.V.S. Murthy 6/6/82

Cochin -11

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## A C K N O W L E D G E M E N T S

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# PHYSICAL CHARACTERISTICS OF THE COASTAL WATERS OFF THE SOUTH-WEST COAST OF INDIA WITH AN ATTEMPT TO STUDY THE POSSIBLE RELATIONSHIP WITH SARDINE, MACKEREL AND ANCHOVY FISHERIES.

## 1. INTRODUCTION

The potential fishery resources of the Indian ocean have been estimated by several workers. Panikkar (1967) estimated that the output which is at present around 2.5 million metric tonnes could reach 20 million metric tonnes per annum towards the close of the century. According to Prasad et al (1969) the potential harvest could be 39-40 million metric tonnes. After considering the present level of world exploitation they have estimated the annual sustainable yield to be around 11 million metric tonnes. Jones and Banerji (1968) have estimated the annual yield from the continental shelf around the Indian sub-continent. (Table-1)

The UNDP/FAO Pelagic Fishery Project has estimated the average mackerel and oil sardine resources within the Project area along the south.west coast of India (between Ratnagiri on the west coast and Tuticorin on the south-east coast) to be of the order of 300,000 and 400,000 tonnes respectively. Existence

Table-1.

**Estimated annual yield of marine fishery resources from the Continental shelf around the Indian Sub-continent.**

| Region | Present production(t) Demersal | Present production(t) Pelagic | Present production(t) Total | Estimated Production(t) Demersal | Estimated Production(t) Pelagic | Estimated Production(t) Total |
|---|---|---|---|---|---|---|
| West coast of India | 180,000 | 470,000 | 650,000 | 577,000 | 1,020,000 | 1,597,000 |
| East coast of India | 65600 | 147000 | 212600 | 143000 | 672000 | 815000 |
| Lakshadweep & Maldives | Negligible | 16000 | 16000 | 7000 | 22000 | 29000 |
| Andaman & Nicobar | 100 | 200 | 300 | 4000 | 8000 | 12000 |

of resources of considerable magnitude of anchovy (white-bait), cat fish, ribbon fish, horse mackerel and shallow water mix comprising of silver bellies, golden scad, butter fish etc, were revealed during the investigations conducted by the Project (1971-1978). Of these, white-bait was most dominating with an average standing stock of over 400,000t. Horse mackerel and cat fish/ribbon fish resources indicated an average standing stock of 144,000t and 155,000t respectively. According to the Project, the present level of exploitation is far below the average stock position in the case of mackerel, oil sardine and white-bait.

Availability of resources is perhaps the most important factor which determines the success of any industry. In the case of the fishing industry, at the basic production level, the availability of fishable concentrations of fishes and other commercially important marine life is the decisive factor which controls the economy of the whole system. Even when well equipped vessels, fishing gear and skilled personnel are available, the success of the industry is dependent on the availability of fishable concentrations of commercially important marine life within a specified area. By the word "fishable concentrations", the implication is the availability of sizeable quantities of fishes which could be definitely caught using a particular type of craft and gear in a particular area within a specified time. Naturally with the availability of fishable concentrations of commercially important marine life, the chances of getting a comparatively good catch are always high. Hence the above factor assumes great significance at the basic production level of the industry.

Of late, it has been accepted that a reasonable solution to the problems of stock and recruitment, interaction between different species and inherrent variability of natural systems will help us to manage the fisheries in a better way rather than basing the entire concept on maximum sustained yield. (Gulland, 1977). Considerable amount of data has been gathered on the life history of various species and also their environmental requirements and behaviour and several attempts have been made in the past to translate the results into practical application for the economic benefit of fisheries. This resulted in the recognition of a separate branch of fisheries environmental services with the basic objective of assisting fishermen in better planning for fishing operations and also in searching for fishable concentrations. Such a service will help to minimise the searching time, thereby reducing the running expenses for both craft and crew. The net result would be a proportionate lowering of prices which in turn would make cheaper fish protein available to low income groups of developing countries.

As in the case of terrestrial animals, the marine fauna including fishes also respond in varying degrees to changes in the environmental conditions. The physical parameters such as sea water temperature, density, hydrostatic pressure, horizontal and vertical movement of water masses, the intensity and penetration of solar radiation at different levels and chemical parameters such as the saltiness of sea water, dissolved gases, distribution of nutrients etc. and biological factors such as the availability of food, presence of predators etc. decide the occurrence, distribution, abundance, migration, reproduction and mortality of individual species in space and time.

Japan was one of the first countries which recognised the importance of synoptic information on oceanographic and ocean climatological conditions and also their application for the improvement of fisheries. The valuable contributions made by Laevastu and Hela (1970) assume great significance in this context.

The productivity of a particular region of the sea is dependent on the replenishment of the waters by plant nutrients either along the horizontal or vertical plane. Within the euphotic zone the availability of nutrients such as phosphates, nitrates and silicates.is perhaps one of the most important factors controlling phytoplankton production which in turn affects the production of zooplankton and ultimately the entire animal community including fishes in a specific area of the sea. As most of the commercially important fishes and other marine life are either directly or indirectly dependent on the phytoplankton production, replenishment of the surface layers (euphotic zone) by plant nutrients either along the horizontal or vertical plane is perhaps the most important factor which controls the availability of seafood in a particular area of the sea.

The above mentioned replenishment of the surface waters by nutrients from elsewhere is possible only by the horizontal or vertical transport of the water masses. The same is more or less true of essential dissolved gases (dissolved oxygen). The vertical mixing process within a waterbody is, to a certain extent, controlled by the vertical stability conditions, which in turn makes a particular region of the sea fertile or barren. As pointed out earlier by Cooper (1960), the replenishment of the surface waters of the oceans by nutrients from below is dependent on the stability of the water column. Upwelling of nutrient-rich bottom (sub-surface) waters to the surface layers helps in the replenishment of the euphotic zone by nutrients from below. As the vertical mixing process in the sea would be governed by the vertical stability parameter observed within a water column, a proper assessment of this parameter will help to find out probable areas of upwelling and diverging current systems. This might help the prediction of probable areas of fish concentrations, especially large shoals of some of the commercially important plankton feeders such as oil sardine, mackerel, anchovy etc.in the area under observation during a specific period. Such a prediction system assumes special significance especially at a time when the country is launching an ambitious programme for the commercial exploitation of fishable concentrations of pelagic fishes such as sardine, mackerel, anchovey, tuna etc. around the sub-continent within the Exclusive Economic Zone (EEZ)

Aim of the present study:

The present study is aimed at observing the variations, in space and time, of some of the important hydrographic parameters such as sea water temperature, salinity and dissolved oxygen withinthe coastal waters along the south-west coast of India between Ratnagiri (17°00'N,73°20'E) and cape comorin ( 8°10'N,77°30'E). Specific data relating to the process of upwelling and sinking was collected mainly to evaluate the extent and intensity of the vertical mixing processes active in the area under study. The study also attempted possible correlations between the observed parameters and the occurrence and migrations of some of the major pelagic fishery resources such as sardine, mackerel and anchovy in the area under study.

Background information:

Several investigations were reported for the area selected for the study and adjacent waters with major contributions from Hornel (1910), Devanesan (1943), Chidambaram and Menon (1945), Panikkar (1949), Bhimachar and George (1950), Chidambaram and Rajendran (1951), George (1953), George (1958), Subramonyan (1959), Banse (1959), Ramasastry (1959), Carruthers (1959), Ramamirtham and Jayaraman (1960), Edelman (1960), Ramasastry and Myrland (1960), Pradhan and Reddy (1962), Vinogradov (1962), Nejman (1963), Ramamirtham and Nair (1964), Patil et al.(1964), Murthy (1965), Ramamurthy (1965). Rao and Jayaraman (1966), Sharma (1966,1968), Subramonyan and Sarma (1967), Wooster, et al.(1967), Varadachari and Sharma (1967), Darbyshire (1967), Banse (1968), Anand et al. (1968), Reddy and Shankaranarayanan (1968), Prasad (1969), Mukundan (1971), Wyrtki (1971), Prabhu et al. (1972), Noble (1972), Nair et al. (1973), Subramonyan (1973), Rao et al.(1973), Antony Raja (1974), Pillai and Perumal (1975), Menon and George (1977) etc.

Besides, some detailed studies were made in the coastal waters of the south-eastern Arabian Sea using Research vessels "Kalava", "Conch" and "Varuna". The relevant departmental reports (classified) brought out by the Naval Physical and Oceanographic Laboratory (erstwhile Indian Naval physical Laboratory), Cochin (Sundararamam et al. 1963, 1964), the various reports published by the erstwhile UNDP/FAO Pelagic Fishery Project, Cochin, relevant reports pertaining to the International Indian Ocean Expedition, the reports/bulletins brought out by the Central Marine Fisheries Research Institute, Cochin, Exploratory fisheries Project, Bombay, Integrated Fisheries Project, Cochin, Department of Marine sciences, University of Cochin and the National Institute of Oceanography, Goa are worth mentioning in this context.

Approximately 1350 km of the coastline bordering Maharashtra, Goa, Karnataka, Kerala and Tamil Nadu fall within the area under study. The continental shelf is comparatively narrow in the south and becomes wider towards north. Off Ratnagiri the outer edge of the continental shelf is located about 80 nautical miles away from the coast where as off Quilon and Cochin the same lies about 30 nautical miles away.

The annual average catch of marine fish in India (1971-1975 figures) is estimated to be around 1.2 million metric tonnes (CMFRI) of which almost 50% are landed within the area under study. Table-2 indicates the relative importance of the exploited fishery resources in the area based on average annual figures.

Table- 2

Annual average fish catches (1971-1975) in the area under study and the proportionate contribution of the Major categories of fish

| Sl. No. | Category | Average annual catch (t) from the area under Survey | Proportionate contribution of different Categories (%) |
|---|---|---|---|
| 1. | Oil Sardine | 1,52,303 | 24.07 |
| 2. | Other Clupeids | 66,754 | 10.55 |
| 3. | Mackerel | 83,477 | 13.19 |
| 4. | Other Scombroids | 13,306 | 1.79 |
| 5. | Ribbon Fish | 31,083 | 4.91 |
| 6. | Cat Fish | 30,478 | 4.82 |
| 7. | Sciaenids | 19,232 | 3.04 |
| 8. | Elasmobranchs | 16,766 | 2.65 |
| 9. | Silver Bellies | 16,574 | 2.62 |
| 10. | Carangids | 13,422 | 2.12 |
| 11. | Perches | 12,696 | 2.01 |
| 12. | Flat Fishes | 9,382 | 1.48 |
| 13. | Lizard Fishes | 5,292 | 0.84 |
| 14. | Crustaceans | 1,02,671 | 16.23 |
| 15. | Others | 61,240 | 9.68 |
| | Total | 6,34,676 | 100.00 |

## 2. DATA AND METHODS

The relevent basic hydrographic, plankton and fishing data collected onboard fishery research vessels " R.V.Rastrelliger "and " R.V.Sardinella" attached to the erstwhile UNDP/FAO Pelagic fishery Project, Cochin during the period 1971-1978 and " R.V.Varuna" attached to the Integrated Fisheries Project, Cochin during the period 1971-1973 were made use of in the present study. The area chosen for the study along with the location of oceanographic sections/ stations covered during the period 1971-1978 are given in Fig.1. The number of times each section was covered during the above period is given in Table-3.

Most of the sections cover only the area occupied by the continental shelf within a distance of approximately 50 n.miles. These nearshore waters are, however, important because they constitute the environment for significant part of the Indian fisheries. Considerable seasonal variations are also characteristic of this environment.

It may be observed from the above Table (Table -3) that the Cochin section was covered the maximum number of times (65). Observations were made at ~~the~~ first (1971-1973) onboard the research vessels " Sardinella" and " Varuna " and later (1973 - 1978) onboard "Rastrelliger ". The water sampling for salinity and dissolved oxygen estimations and sea water temperature observations were made at standard depths up to a maximum of 500m. using Nansen Reversing water bottles. The stations within the continental shelf were fixed at an interval of 10 n.miles at right angles to the coast line and off the shelf the

F I G. 1

Map showing the location of oceanographic sections/stations.

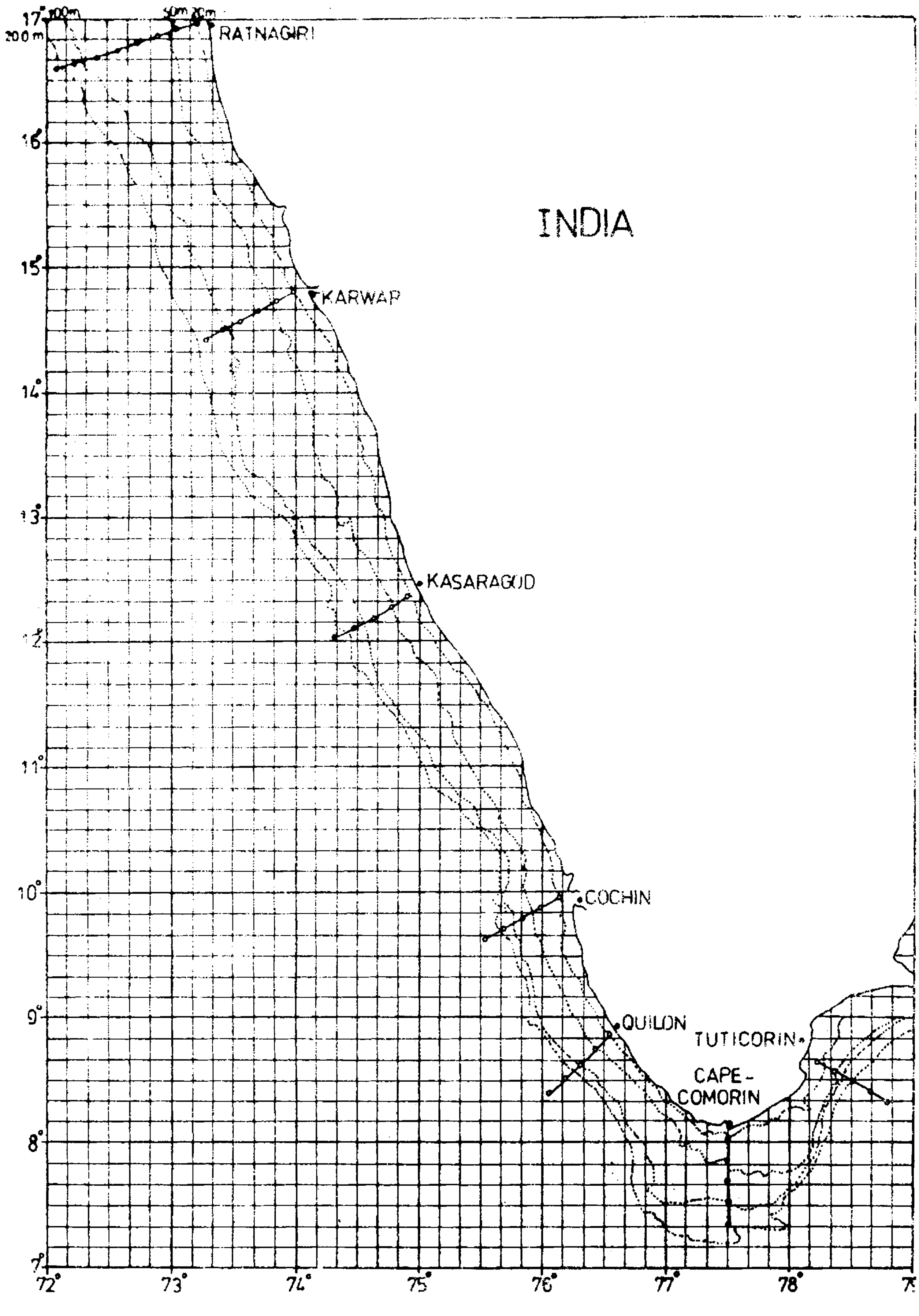

INDIA
RATNAGIRI
KARWAR
KASARAGOD
COCHIN
QUILON
TUTICORIN
CAPE-
COMORIN
200m
100m
50m
20m
17°
16°
15°
14°
13°
12°
11°
10°
9°
8°
7°
72°
73°
74°
75°
76°
77°
78°

Table. 3

Coverage of the different Oceanographic Sections during the period 1971-1978.

| | No. of coverages made during 1971-'78 | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|
| | '71 | '72 | '73 | '74 | '75 | '76 | '77 | '78 | (1971-'78) |
| Ratnagiri | - | 5 | 5 | 7 | 5 | 1 | 3 | 2 | 28 |
| Karwar | 2 | 10 | 8 | 6 | 5 | 6 | 3 | 3 | 43 |
| Kasaragod | 2 | 9 | 7 | 6 | 5 | 5 | 2 | 2 | 38 |
| Calicut | - | 6 | 4 | - | - | - | 1 | 1 | 12 |
| Cochin | 10 | 11 | 10 | 9 | 9 | 6 | 5 | 5 | 65 |
| Quilon | 2 | 8 | 7 | 7 | 5 | 2 | 1 | 2 | 34 |
| Cape-comorin | - | - | 6 | 7 | 6 | 4 | 2 | 2 | 27 |
| Tuticorin | - | - | 5 | 7 | 4 | 2 | 1 | 1 | 20 |

interval was 30 n.miles. Special care was taken to ensure that the different sections were covered within the shortest possible time to get synoptic picture of the hydrographic conditions during each survey. During 1971-1972 salinity estimations were made by the standard titration method. However from 1973 onwards a salinometer was used. A quality analysis of temperature and salinity data unfortunately established too large a scatter in the salinity determination done by titration method in 1971 and 1972. Therefore no salinity values estimated during 1971 and 1972 are included in this report.

The standard Winkler method was used for dissolved oxygen measurements. Nansen Reversing thermometers were used in pairs to minimise possible errors. Bathythermograph observations using either a shallow, medium or deep Bathythermograph were also made at all the stations except the shallowest station located near the coast. Estimations of the top depth and width of the main thermocline were made from the bathythermograms. Standard nomograms were used for estimating the density (Sigma-t) values. The vertical stability parameter was calculated by employing the Hesselberg and Sverdrup fomula (1942).

Plankton samples were collected employing standard sampling gear viz. Bongo-20 (20cm. diameter net) and Bongo-60 (60cm.diameter net) both fitted with nylon nets of 0.5mm mesh size and equipped with calibrated flow meters. The bongo nets were operated in continuous oblique hauls at minimum winch speed and 2-3 knots vessel speed. The samples were preserved in 5% formaline. From the flow meter readings and the measured wet desplacement volumes of the samples, the mean density of plankton in $ml/m^3$ of water filtered was computed.

Acoustic surveys and fishing experiments for identification and sampling were undertaken onboard the two project vessels "Sardinella" and "Rastrelliger". When the smaller vessel "Sardinella " surveyed the shallow parts of the shelf upto 40m.depth, at 7.5 n. miles cruise track intervals, the larger vessel "Rastrelliger" covered the deeper parts of the shelf and the continental slope with the cruise track interval at 15 n.miles. Both the vessels were fitted up with SIMRAD Scientific Sounders EK-38 (deep water) and EK-120 and QM Echo Integrators. On the basis of the patterns of recording and the results of relevant fishing experiments, the integrator readings were allocated to different groups of fishes.

"Rastrelliger" used 4 types of bottom trawls viz high opening bottom trawl, hard bottom trawl, small high opening bottom trawl and a Lobster bottom trawl. The vessel used a standard pelagic trawl as well as mid-water trawl for catching myctophids. "Sardinella" used two types of high opening bottom trawls and one type of pelagic trawl. This vessel also operated the purse-seine and the gill seine. Fishing was always carried out based on recordings of the echo sounder and the Sonar. Depth of operation in the case of pelagic trawl was decided by operating the trawl sonde. Usual trawling speed was about 3 knots. The specifications of the two research vessels "Rastrelliger" and "Sardinella" are given in Table-4 and Table-5. The broad specification of fishing gear employed onboard is given in Table -6.

The vertical time sections for sea water temperature and dissolved oxygen were prepared separately for the coastal station, middle shelf and outershelf stations in respect of Ratnagiri, Karwar,

Table-4

## Specifications of "R.V. RASTRELLIGER"

Stern ramp trawler type combination trawler-cumpurse-seiner-cum oceanographic research vessel with refrigeration and cold storage facilities. Built in 1972-in Norway.

| | |
|---|---|
| Length overall (L.O.A.) | 46.45 m |
| Breadth | 9.00 m |
| Depth | 6.50 m |
| Draught | 4.35 m |
| Hold capacity | 210 $m^3$ |
| Cold storage capacity | 43 $m^3$ |
| Net tonnage | 109.77 |
| Gross tonnage | 309.0 |
| Fuel oil capacity | 124 $m^3$ |
| Fresh water tanks | 46 $m^3$ |
| Fresh water production | 3 $m^3$/day |
| Main engine power | 1320 HP |
| Auxiliary engines-2 nos. driving two gnerators | 174 HP each |
| Speed | 12.2 knots |
| Trawl, purse seine and hydrographic winches and Deck crane 1.5 ton. | Hydraulic |
| Electronic fish finding and acoustic equipments | 2 echo sounders<br>1 sonar<br>1 Net sonde<br>1 Echo integrator |
| Special Navigation equipments | Radio direction finder (RDF)<br>Auto-Pilot<br>Gyrocompass<br>Electrical steering<br>Radar<br>Radio-Telephone |
| Accommodation | 24 men |
| Endurance at sea | 3 weeks. |

Table-5

Specifications of "R.V. SARDINELLA"

Combined trawler/purse-seiner built in fibre glass reinforced polyester. Year of built-1969, in Norway.

| | |
|---|---|
| Length overall (L.O.A.) | 16.34 m |
| Breadth | 4.50 m |
| Depth | 2.45 m |
| Draught | 2.12 m |
| Tonnage (Gross) | 30.26 |
| Fuel oil capacity | 5 tonnes |
| Fresh water capacity | 1.4 tonnes |
| Main engine power | 153 HP |
| Speed | 9.5 knots |
| Electronic fish finding equipments | 2 sonars<br>1 echo sounder |
| Special navigation equipments | Radio direction finder<br>Autopilot, Radar<br>Radio Telephone |
| Trawl, purse-seine and hydrographic winch | Hydraulic |
| Accommodation | 9 men |
| Endurance at sea | 7 days. |

Table-6

Specifications of Fishing gear employed onboard "R.V. RASTRELLIGER" and "R.V. SARDINELLA" (1971-1978)

| Name of vessel | Type of gear | Specifications of gear: No. of meshes in mouth circumference | Specifications of gear: Mesh size (stretched) mm |
|---|---|---|---|
| R/V Rastrelliger | Hard bottom bobbin trawl (Granton trawl, FAO gear design catalogue, 1972, P.68) | 400 | 140 |
| | High opening bottom trawl | 1500 | 40 |
| | Deep sea bottom trawl, 50 m | 700 | 120 |
| | Myctophid mid-water trawl | 616 | 400 |
| R/V Sardinella | Bottom trawl (Engel, FAO gear design catalogue, 1972, P.52) | 294 | 160 |
| | Bottom trawl (Engel, FAO gear design catalogue, 1972, P.48) | 300 | 120 |
| | Pelagic trawl (6 X 6 fathoms) | 756 | 151 |

| Name of vessel | Type of gear | Length (m) | Height (m) | Mesh size (m) |
|---|---|---|---|---|
| R/V Sardinella | Small purse-seine | 320 | 40 | 20 |
| | Large purse-seine | 500 | 40 | 20 |
| | Gill seine | 500 | 20 | 40 |

Kasaragod, Cochin, Quilon and Cape-Comorin sections.

The data pertaining to the Tuticorin section has been utilised mainly to check the continuity of certain hydrographic parameters around the southern tip of the sub-continent. The Calicut section was covered only during certain years with a view to check the progress of the upwelling phenomenon and the associated biological activities.

The plankton biomass, fishing and acoustic survey results available in the Pelagic Fishery Project records were also made use of for correlation studies.

The author, in the capacity of Senior Oceanographer in the erstwhile Pelagic Fishery Project made an attempt to organise special hydrography/plankton/fishing surveys within the area under study during the south-west monsoon to assess the intensity of the process of upwelling and to establish possible correlations between the occurrence of oilsardine, mackerel and anchovy and the variations noticed in the relevant environmental parameters observed in space and time. It is worth mentioning in this context that the data used in the present study have been collected onboard the fishery research vessels mentioned above employing more or less the same standard oceanographic equipments/ instruments, plankton samplers and fishing gear and hence were comparable within reasonable limits. Whereever doubts were indicated the specific data were rejected. Inorder to minimise the fluctuations in the various environmental parameters which are likely to arise out of coastal processes and also diurnal influence, it was decided to consider the parameters at the second station from the coast at a depth of 10m. as representative of the conditions characteristic of the surface layers near the coast.

## 3. RESULTS AND DISCUSSION

### Hydrographic Conditions:

Hydrographic data collected from the Oceanographic sections located off Ratnagiri, Karwar, Kasaragod, Cochin, Quilon and Cape-Comorin provided fairly good information on the seasonal fluctuations noticed on the shelf.

### Ratnagiri Section:

Data pertaining to eight stations (spaced at an interval of 10 nautical miles) collected during the period 1972-1978 covering the entire shelf region off Ratnagiri was utilised for the study. The mean monthly sea surface temperature (at a depth of 10m. at the second station from the coast) ranged between 26.50°C and 30.03°C. The maximum was observed in May and minimum in February. The surface mixed layer, on an average, extended to a depth of 39m. during December-January-February. The mixed layer has become non-existent or comparatively very shallow with minimum thickness (11m.) during October-

November. Thermal inversions were characteristic of the surface layers ( 40-150m) during the period December-March.

The mean monthly sea surface salinity varied between 34.78‰ and 36.02‰. The maximum was observed in the month of May and the minimum in October. Salinity conditions were found to be closely related to the influence of the low salinity equatorial waters in the northerly current and the advection of the high saline northern Arabian sea waters in the southerly current. The salinity maximum characteristic of the tropical oceans was observed between depths of 30-50m. and 100-150m. during the south-west monsoon and post-monsoon season respectively.

The mean monthly sea surface dissolved oxygen values ranged between 4.30ml $O_2$ /L and 5.04ml.$O_2$ /L. The maximum was observed during December and the minimum in September.

The mean monthly sea surface density ( Sigma -t) ranged between $\sigma t$.22.09 and $\sigma t$.23.05. The maximum was observed in December and the minimum in February.

<u>Karwar Section:</u>

Data collected from the first six stations (spaced at an interval of 10 nautical miles) during the period 1971-1978 was utilised for the present study.

The mean monthly sea surface temperature ranged between 23.86$^{o}$c and 30.15$^{o}$c. The minimum was observed during the month of October and the maximum in May. The mixed layer, on an average, extended to a depth of 61m. during December-January-February. The mixed layer became very shallow with minimum thickness (10m.) during October -November. Thermal inversions were present at the surface layers between depths of 40-150m. during December-March.

The mean monthly sea surface salinity varied between 32.90‰ and 36.12‰. The maximum was observed during May and the minimum in January. The salinity characteristics of the surface layers were found to be influenced by the southerly and northerly seasonal-current systems which carried high saline Arabian sea waters southward and low-saline equatorial waters northward. The salinity maximum was found between depths of 30m.(south-west monsoon) and 150m.(post-monsoon).

The mean monthly sea surface dissolved oxygen values ranged between 1.39 ml $O_2$/L and 5.35 ml $O_2$/L. The minimum was associated with the peak upwelling period ( October ) and the maximum just prior to the upwelled water reaching the surface layers ( September ).

The mean monthly sea surface density (sigma -t) off Karwar ranged between $\sigma t$.21.15 and $\sigma t$.23.86. The minimum was observed in January and the maximum in October associated with the presence of high-density upwelled water at the surface levels.

<u>Kasaragod Section:</u>

Data pertaining to the first five stations (spaced at an interval of 10 nautical miles) collected during the period 1971- 1978 was utilised for the study. The mean monthly sea surface temperature ranged between 21.78$^\circ$c and 29.70$^\circ$c. The minimum was observed during September and the maximum during April. The minimum values were associated with the upwelling of sub-surface waters to surface levels during the south-west monsoon and the maximum during the summer season. The mixed layer, on an average, extended to a depth of 56m. during December-January-February and became very shallow with minimum thickness (13m) during June-July-August-September. Thermal inversions were characteristic of the surface layers during the period December-March.

The mean monthly sea surface salinity varied between 32.71‰ and 35.55‰. The minimum values were observed during January and the maximum during May. The salinity maximum characteristic of tropical oceans was found at depths between 30m.(south-west monsoon ) and 150m.(post-monsoon)

The mean monthly sea surface dissolved oxygen values varied between 1.10ml $O_2$/L and 4.98 ml $O_2$ /L. The minimum was associated with upwelling of poorly aerated bottom waters to the surface levels in September and the maximum during December when the process of sinking became active in the area.

The mean sea surface density off Kasaragod ranged between $\sigma_t$.20.87 and $\sigma_t$.24.52. The minimum as observed in January and the maximum in September associated with the presence of high density upwelled water at the surface levels.

Cochin Section:

Data collected from the first five stations (located at an -

interval of 10 nautical miles) covered during the period 1971- 1978 was utilised for the study.

The mean monthly sea surface temperature varied between 23.57°c. and 30.01°c. The minimum was observed during September associated with the process of upwelling and the maximum in April, just before the commencement of the south-west monsoon. The mixed layers, on an average extended to a depth of 61m. during December-January-February. The mixed layer became very shallow with minimum thickness (10m.) during June-July-August -September. Thermal inversions were present at the surface levels during December -March between depths of 50-150m.

The mean monthly sea surface salinity varied between 32.50‰ and 35.22‰. The minimum values were observed in December and the maximum in September associated with the presence of high salinity upwelled water at the surface levels. The salinity maximum was observed at depths between 30m (south-west monsoon) and 150m. (Post-monsoon).

The mean monthly sea surface dissolved Oxygen values varied between 2.46ml $O_2$/L and 4.91 ml $O_2$/L. The minimum values were associated with the peak upwelling period in September and the maximum in January when the process of sinking became active at the surface levels.

The mean sea surface density off Cochin ranged between $\sigma_t$ 21.24 and $\sigma_t$ 24.01. The maximum values were associated with the presence of high-density upwelled water at the surface levels during the month of September.

<u>Quilon Section:</u>

Data collected from the first five stations (located at an interval of 10 nautical miles) covered during the period 1971-1978 was made use of in the present study.

The mean monthly sea surface temperature varied between 24.26°c and 29.82°c. The minimum was observed in September associated with the presence of cold upwelled waters at the surface levels and the maximum in April just before the commencement of the south-west monsoon. The surface mixed layer, on an average, extended to a depth of 66m. during December-January-February. The same became very shallow with minimum thickness (16m) during June-July-August-September. Thermal inversions were present at the surface levels during December -March period.

The mean monthly sea surface salinity varied between 33.34‰ and 35.34‰. The minimum values were observed in February and the maximum in October associated with the presence of high-salinity Arabian sea waters at the surface levels. The salinity maximum was observed between depths of 30m (South-west monsoon) and 150m. (Post-monsoon).

The mean monthly sea surface dissolved oxygen values varied between 3.72 ml $O_2$/L and 4.97 ml $O_2$/L. The minimum was associated with the peak upwelling period (July-August) and the maximum in February when the process of sinking became active at the surface levels.

The mean monthly sea surface density off Quilon ranged between $\sigma_t$ 21.16 and $\sigma_t$.23.50. The minimum was associated with the presence of less denser equatorial/Bay of Bengal waters at the surface levels being brought towards higher latitudes in the northerly flow during February and the maximum with the presence of denser upwelled water at the surface levels during September.

Cape-comorin Section:

Data pertaining to the first five stations running due south at rightangles to the coast (spaced at an interval of 10 nautical miles) covered during 1973-1978 was utilised in the present study.

The mean monthly sea surface temperature varied between 21.13°c. and 28.73°c. The minimum was observed during August associated with the presence of cold upwelled waters at the surface levels and the maximum in April just before the commencement of the south-west monsoon. The mixed layer, on an average, extended to a depth of 63m. during December-January-February. The same became very shallow with minimum thickness (20m) during June-July-August-September. Thermal inversions were present at the surface levels during December-March period.

The mean monthly sea surface salinity varied between 33.03‰ and 35.26‰. The minimum was observed during December and the maximum during October.

The mean monthly dissolved oxygen values at the surface levels varied between 2.30 ml $O_2$/L and 4.91 ml $O_2$/L. The minimum values were associated with the presence of Oxygen deficient upwelled waters at the surface levels during August and the maximum in February when the process of sinking became active at the surface levels.

The mean monthly sea surface density off Cape-comorin varied between $\sigma_t$ 24.47, during August associated with the presence of denser upwelled water and $\sigma_t$ 21.38 during December associated with the presence of less-denser equatorial/Bay of Bengal waters at the surface levels.

Tuticorin Section:

Data collected from the first five stations covering the continental shelf area (spaced at an interval of 10 nautical miles)covered during the period 1973-'78 was made use of in the present study.

The mean monthly sea surface temperature varied between 25.72$^{\circ}$c and 29.18$^{\circ}$c. The minimum was observed during August associated with the presence of comparatively colder sub-surface waters at the surface levels and the maximum during April just before the commencement of the south-west monsoon. The mixed layer, on an average, extended to a depth of 78m. during December January-February. The same became shallow with minimum thickness (32 m.) during June-July-August-September.

The mean monthly sea surface salinity varied between 33.94‰ and 35.28‰. The minimum was observed in April and the maximum in October.

The mean monthly sea surface dissolved oxygen values do not indicate any appreciable variation, the minimum being 4.09ml $O_2$/L (May) and maximum, 4.79 ml $O_2$/L (August) indicating the absence of oxygen deficient waters at the surface levels during any particular season.

The mean monthly sea surface density off Tuticorin ranged between σt 20.96 (December) and σt 23.14 (September). The minimum is associated with the north-east monsoon rainfall in the area and also the advection of low salinity Bay of Bengal waters in the southerly current.

Seasonal and spatial variations of major environmental parameters in the area under observation:

Winds:

Along the south-west coast of India the predominant wind direction over the sea shows a gradual change from north-easterly to north-westerly and later to westerly during the period March-April-May (Anonymous 1966). In June the direction changes to south-westerly and westerly with increasing velocities and by July, the velocity reaches Beaufort 5-7. During June-August the predominant wind direction is from south-westerly to westerly. By the end of August the velocity decreases and by October-November the wind starts flowing from north-westerly to east-north-easterly with comparatively low velocities. Both sea breeze and land breeze are common in this area except during the south-west monsoon season.

Currents:

During the south-west monsoon (May-October) there is a southerly flow spread over the entire shelf region. During the change from south-west monsoon to winter a northerly current is established off the shelf. Adjacent to and on the seaward side of the northerly flow, is present a southerly current, limited to the southerly regions.

From winter to summer (February-April) the northerly current vanishes and the circulation breaks up into eddies. The southerly current persists in summer though it is limited to a narrow belt. Once again during the south-west monsoon period this narrow southerly stream spreads over the entire shelf. In general the current during the winter season appears to be stronger than the south-west monsoon current.

During the south-west monsoon period (May-October) the surface current flows southwards along the west coast of India, thereby causing a lifting of the isolines for the different oceanographic parameters (seawater temperature, salinity, dissolved oxygen and density) near the coast. Inorder to satisfy the basic theory of particle motion in relation to the Coriolis force, denser, sub-surface waters from intermediate/ sub-surface levels are slowly induced upwards (upwelling) along the continental shelf to occupy the left hand side of the southerly current (near the coast). This ultimately results in the comparatively denser, cold and low oxygenated sub-surface waters reaching the surface levels near the coast. During this season oxygen deficient waters cover the whole continental shelf area over the bottom.

The southerly current transports comparatively high-salinity Arabian sea waters southwards along the coast, though during the rainy season the addition of fresh water from rainfall and river runoff causes a significant lowering of the surface salinity near the coast.

During the north-east monsoon period (November-March) the surface current reverses it's direction and turns northerly. The northerly current advects low salinity equatorial waters northwards at the surface levels causing a convergence located between latitudes $10^{O}N$ and $12^{O}N$ where the high-saline Arabian sea water sinks below the less-saline equatorial waters. The effect of winter cooling at the surface levels along with the convergence zone lead to the process of sinking. During winter season (January-February) the surface mixed layer covers most of the shelf. For the coastal area south of Bombay the resultant speed of the current is reported to be more than 20 km/day during the south-west monsoon period (Warners, 1952; Banse, 1968). From November to January a northward flowing current is observed. This drift appears to be shallow and seems to have little influence on the waters below the thermocline (Wyrtki, 1973.)

Water masses:

According to Darbyshire (1967) there are three major water masses present on the shelf viz.(1) the Indian Ocean Equatorial water(temperature $17^{O}c$ with a minimum of 34.9‰ salinity) present at the deeper levels on the continental slope (2) the Arabian Sea Water (temperature between $17^{O}c$ and $27^{O}c$, associated with maximum salinity of 35‰ to 36.3‰ and (3) the Equatorial Surface Water (temperature between $27^{O}c$ and $30^{O}c$ and wide salinity range of 30‰ to 34‰). Ramasatry (1959) named it Arabian Sea Surface Water. Banse (1968) indicated that during the peak of south-west monsoon a water-mass is formed by the mixing of low-salinity surface water and the denser upwelled water. The resulting sub-surface water has a lower salinity when compared to the Arabian Sea Water and a wide temperature range down to a minimum of around $20^{O}c$.

Convergence Zone:

The existence of a convergence zone in the area under observation is evident from the horizontal salinity gradients observed during the period January-February-March (Fig.2,3, and 4). In 1974, the sea surface salinity increased from 33‰ to 35‰ between Karwar and Ratnagiri sections. This difference was less pronounced in 1975. In 1973 a similar zone was observed between Kasaragod and Calicut sections.

The variations observed in the sea surface salinity suggest that the convergence zone exhibits seasonal variations spreading northwards with the intensity of the northerly flow which carried equatorial waters towards northern latitudes ( Darbyshire, 1967). During the southwest monsoon season the salinity distribution at the surface levels is not indicative of the convergence zone mainly due to the effect of rainfall and river runoff.

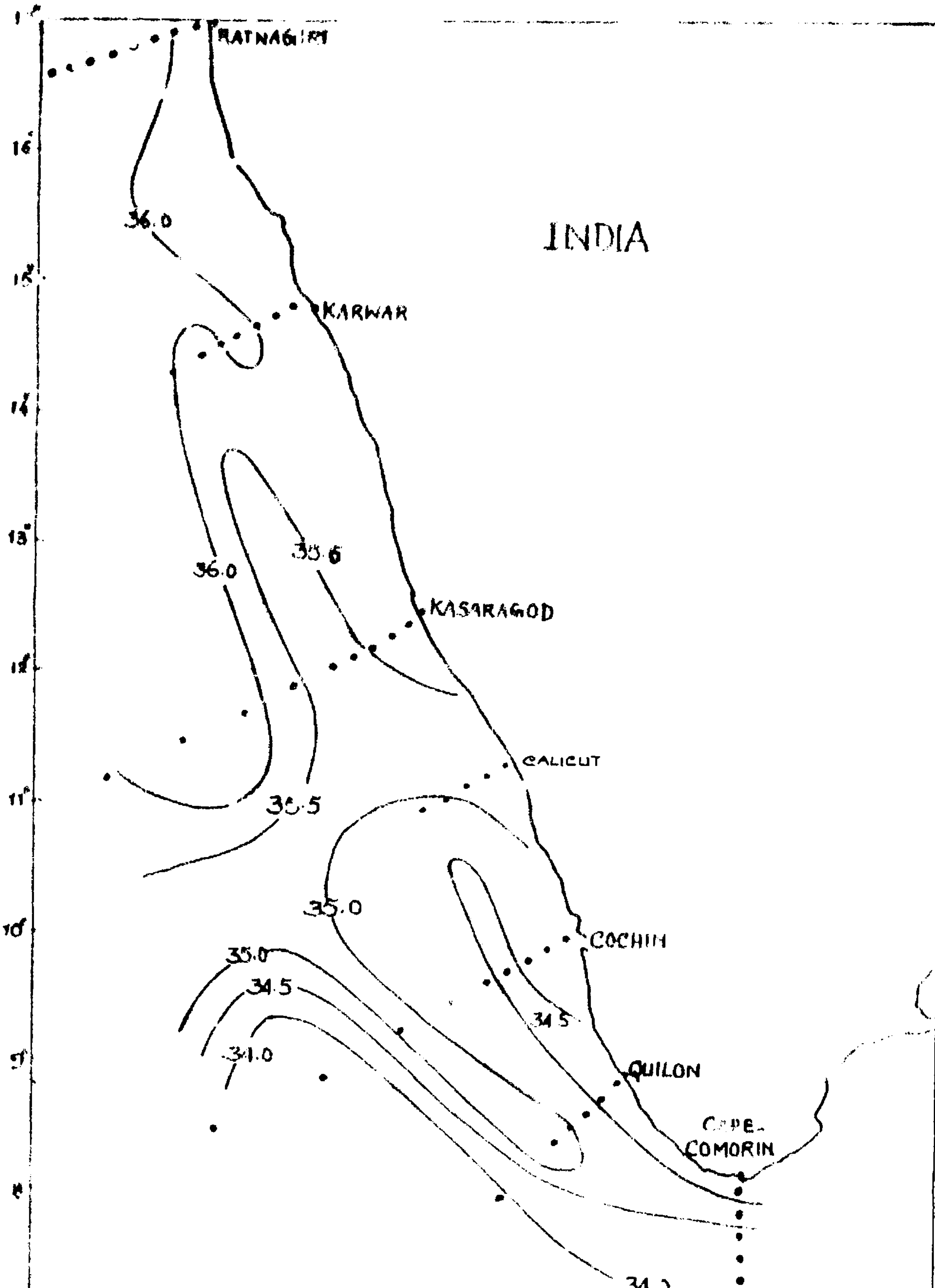
Seawater Temperature:

The monthly mean sea surface temperature for the period 1973 - 1978 shows large variations in space and time(Table-7). In general comparatively low values were observed during January-February-and July-October, the lowest being in August (21.13$^{o}$c) off Cape-comorin. High values at different sections were observed during the month of May, the maximum being 30.15$^{o}$c off Karwar. The high values were associated with the summer season, just prior to the onset of the southwest monsoon. A steady increase in the highest monthly mean temperature (1973-1978)from south to north was noticed between Cape-comorin

F I G. 2

Horizontal distribution of sea surface salinity

(January-March, 1973)

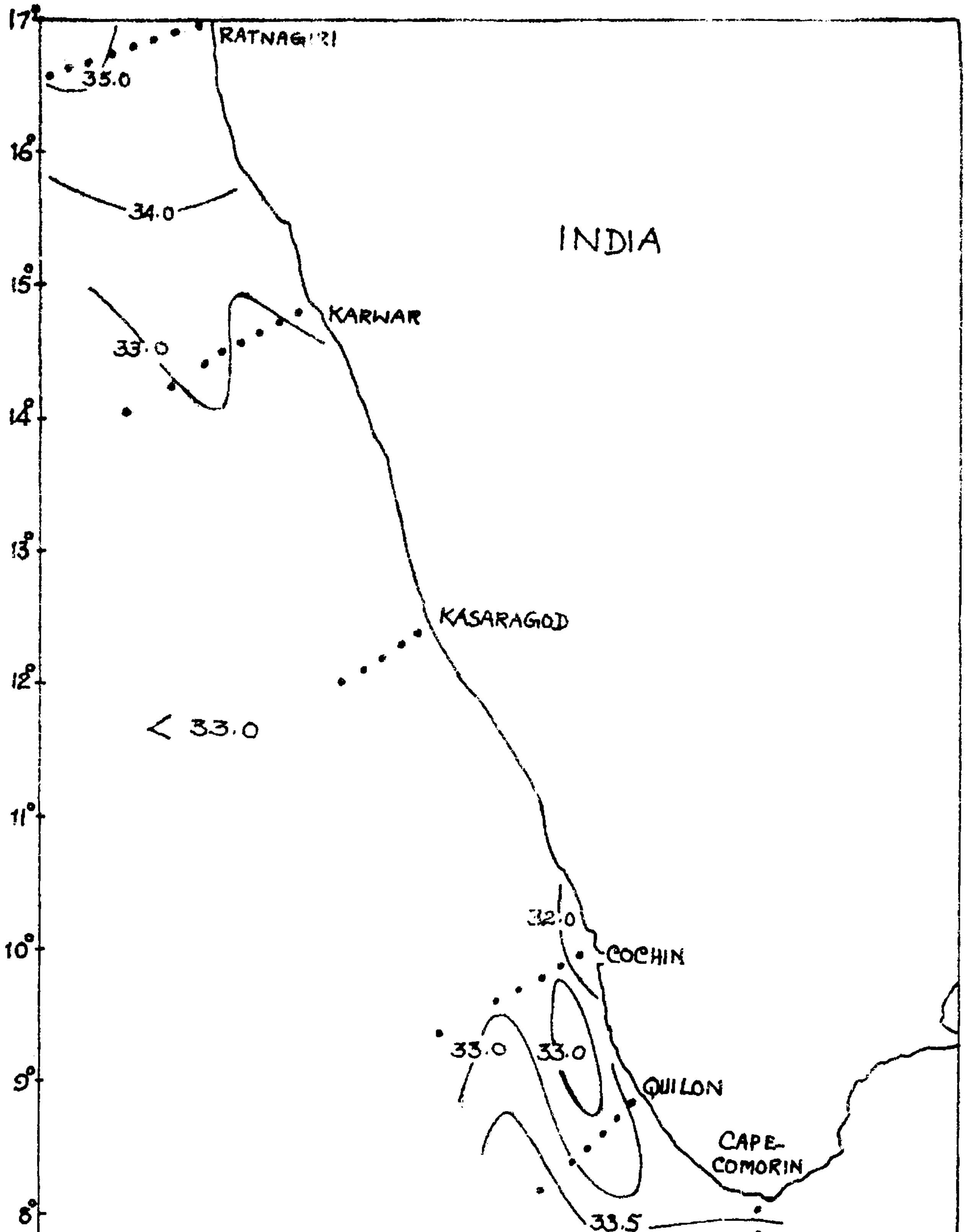


INDIA
RATNAGIRI
KARWAR
KASARAGOD
CALICUT
COCHIN
QUILON
CAPE COMORIN
36.0
36.0
35.6
35.5
35.0
35.0
34.5
34.5
34.0
34.0
72°
73°
74°
75°
76°
77°
78°
79
16
15
14
13
12
11°
10
9
8
7

FIG. 3

Horizontal distribution of sea surface salinity

(January-March, 1974)

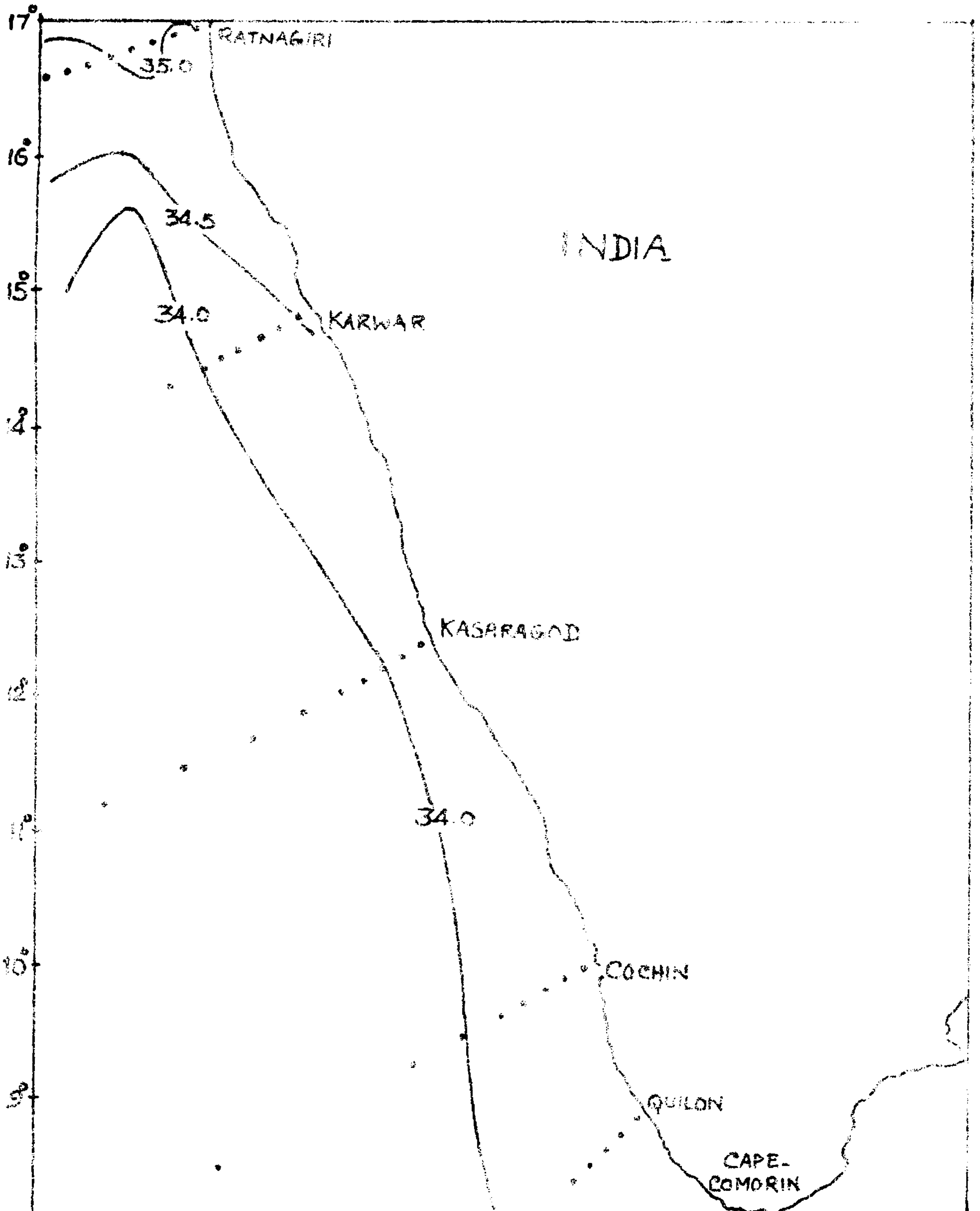


INDIA
RATNAGIRI
KARWAR
KASARAGOD
COCHIN
QUILON
CAPE COMORIN
35.0
34.0
33.0
< 33.0
32.0
33.0
33.0
33.5
34.0
17°
16°
15°
14°
13°
12°
11°
10°
9°
8°
7°
72°
73°
74°
75°
76°
77°
78°
79°

F I G. 4

Horizontal distribution of sea surface salinity

(January-March, 1975)



RATNAGIRI
35.0
34.5
INDIA
34.0
KARWAR
KASARAGOD
34.0
COCHIN
QUILON
CAPE COMORIN
34.0
17°
16°
15°
14
13
12
11°
10°
9°
8°
7°
72°
73°
74°
75°
76°
77°
78°
79°

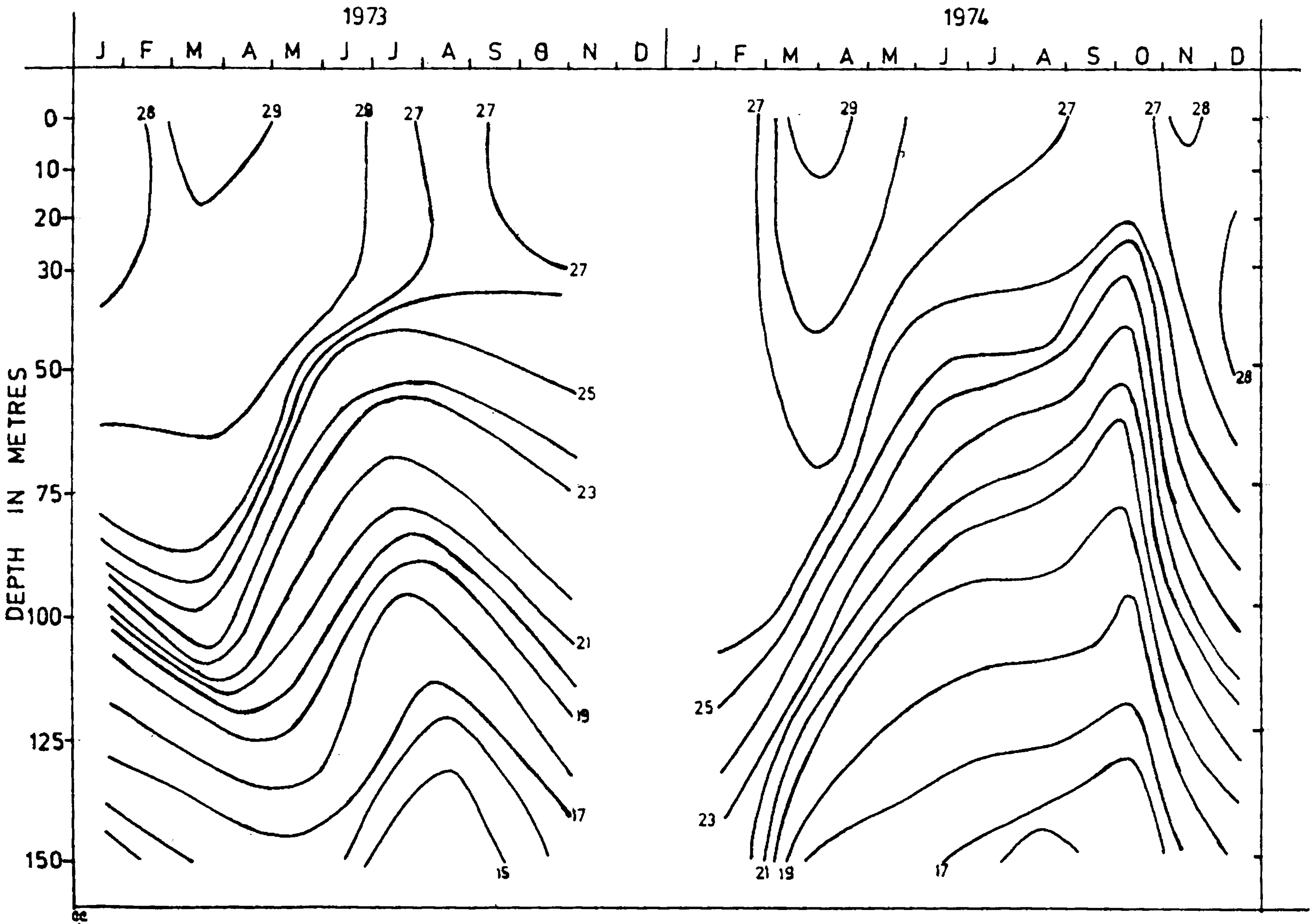
and Karwar(28.73 to 30.15°c). The low values were noticed during January - February and also during the peak upwelling season (July-October). The lowest values were observed in those areas where the intensity of upwelling was comparatively high ( Between Cape-comorin and Kasaragod).

The mean depth of the top of the thermocline show large variations from season to season (Table-11). The top of the thermocline was deepest during the period December, January-February and the same reached the surface layers during June-September (south of Cochin ) and October -November (north of Cochin). Off Tuticorin the vertical osciallation of the top of thermocline was between 32m.(June-September) and 78m.(December-February).

Off the south-west Coast of Africa it was observed that the thermocline, in general, is shallow during Summer, deep during the spring and deepest during the winter (Duncan, 1964). The vertical time sections of sea water temperature for sections representing the southern region (Capecomorin and Quilon-Fig.5 and 6), Central region (Cochin- and Kasaragod Fig. 7 and 8) and the northern region (Karwar and Ratnagiri Fig. 9 and 10) were made use of to compare the variations noticed in the vertical movement of the various isotherms in space and time. The net vertical movement was estimated from the oscillations of the 23°c isotherm which exhibited the maximum movement on the vertical plane. (Table- 12). A comparison of the mean upward movement of the isotherm for the period 1973-1978 indicated the maximum (110 m.) off Quilon and minimum (79 m.) off Cape-comorin. During 1977 (July), the isotherm reached

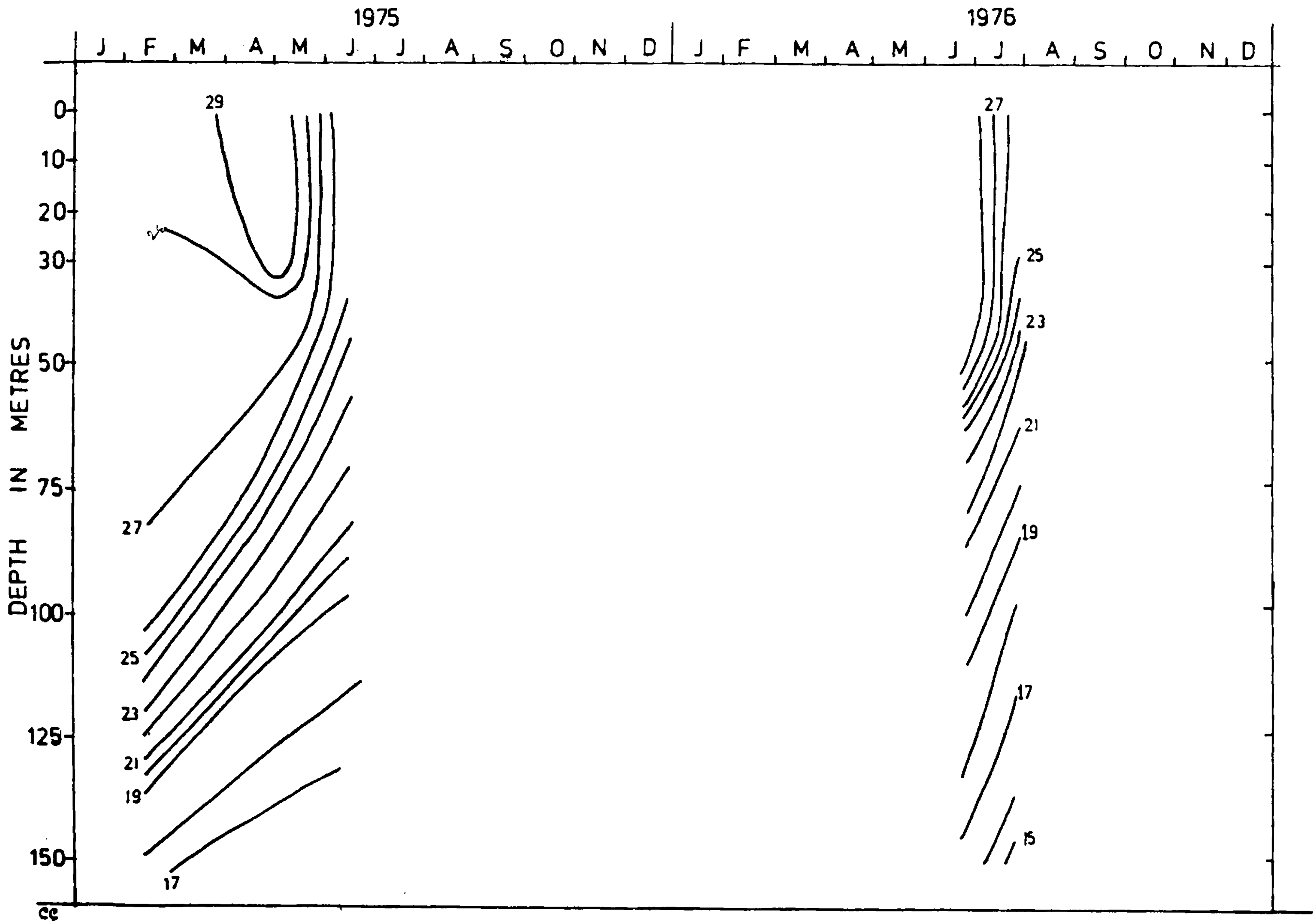
F I G. 5. A

Vertical time section for sea water temperature off Cape-comorin (1973, 1974)


1973
1974
J F M A M J J A S O N D
J F M A M J J A S O N D
DEPTH IN METRES
0
10
20
30
50
75
100
125
150
28
29
28
27
27
27
25
23
21
19
17
15
27
29
27
27
28
28
25
23
21
19
17

F I G. 5. B

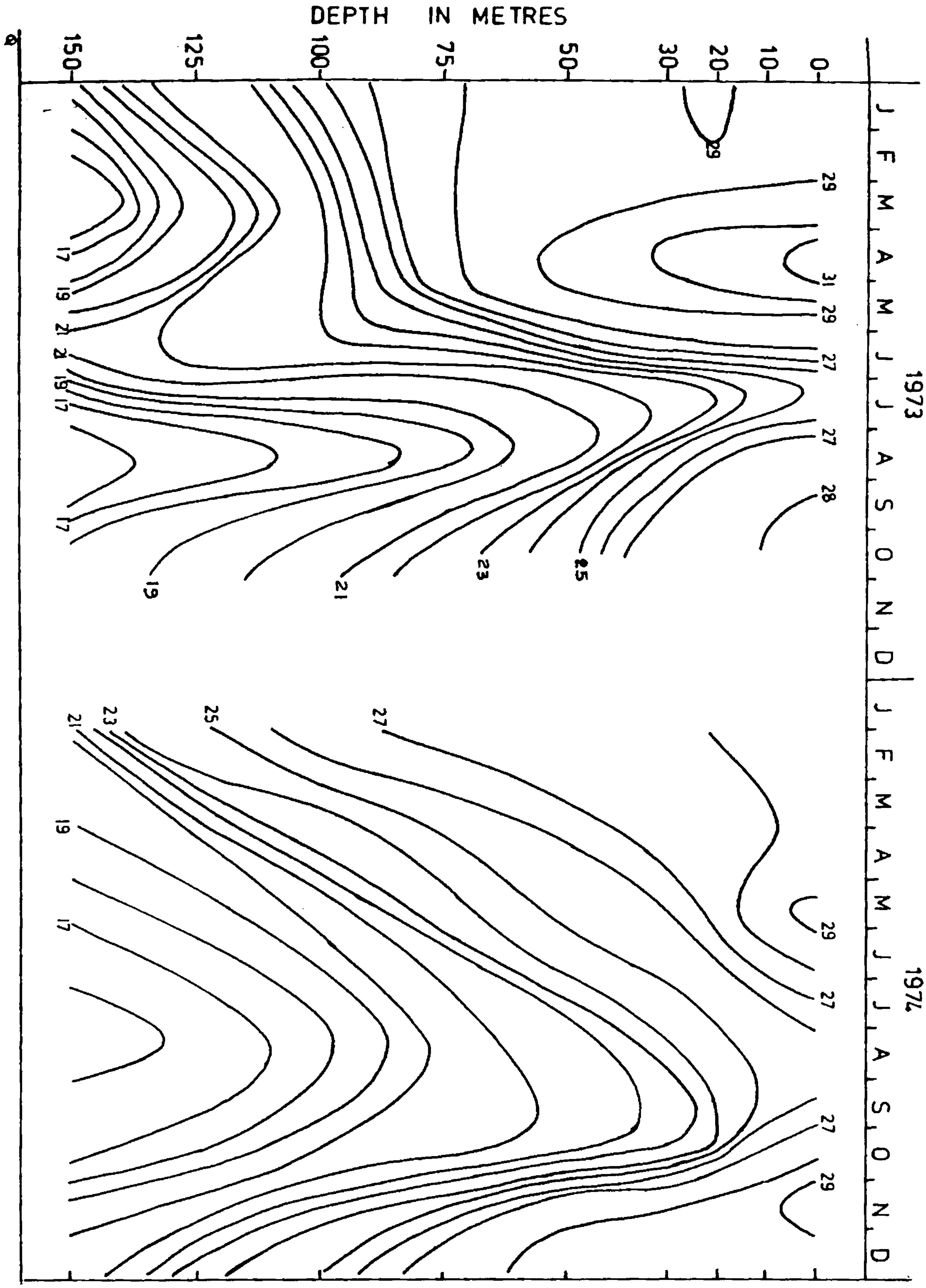
Vertical time section for sea water temperature off Cape-comorin (1975, 1976)


1975
1976
J F M A M J J A S O N D J F M A M J J A S O N D
DEPTH IN METRES
0
10
20
30
50
75
100
125
150
29
27
25
23
21
19
17
15

F I G. 6. A

Vertical time section for sea water temperature

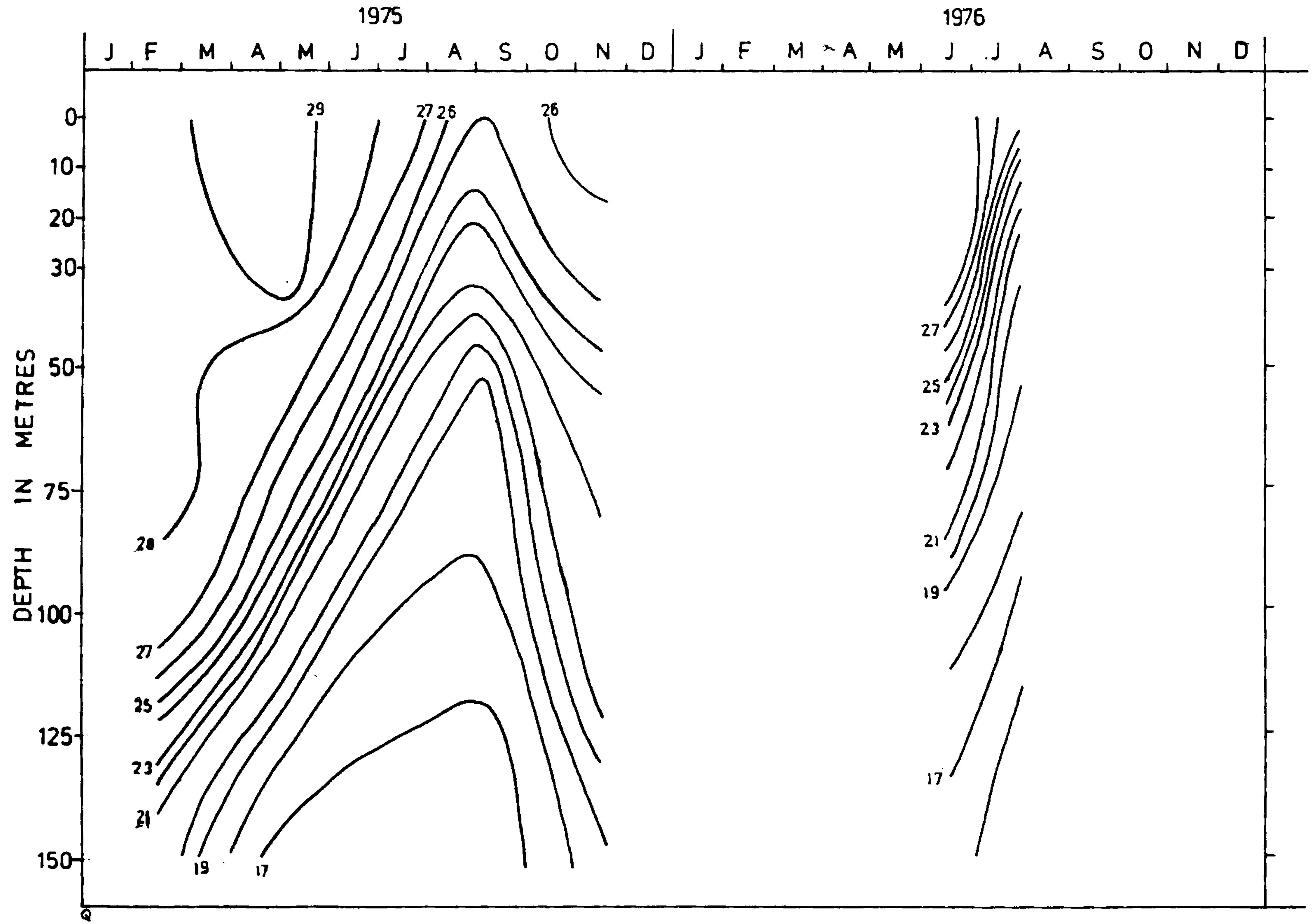
off Quilon (1973, 1974)



DEPTH IN METRES
0
10
20
30
50
75
100
125
150
1973
1974
J F M A M J J A S O N D
29
31
27
28
25
23
21
19
17

FIG. 6. B.

Vertical time section for sea water temperature off Quilon (1975, 1976)

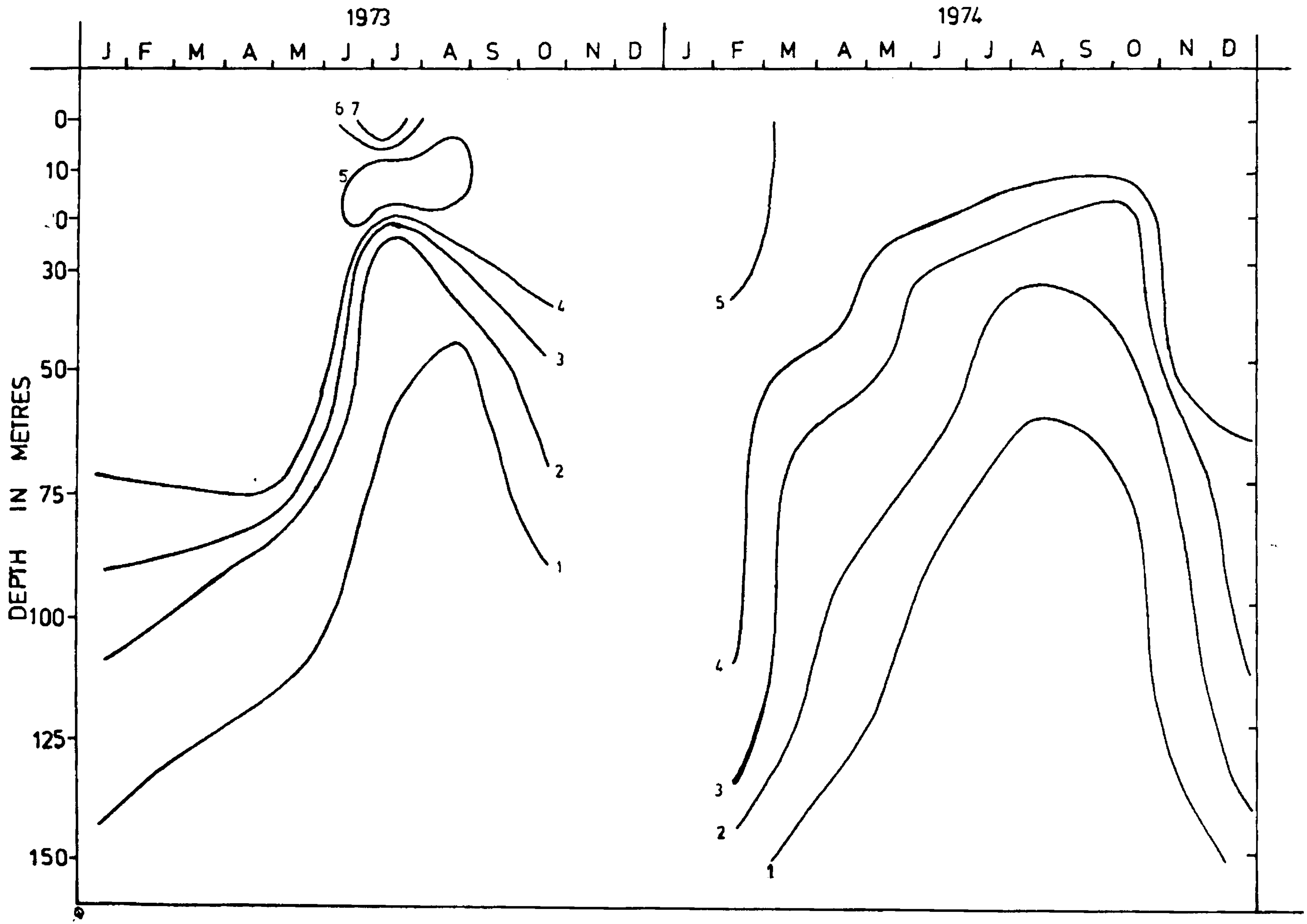


1975
1976
J F M A M J J A S O N D
J F M A M J J A S O N D
DEPTH IN METRES
0
10
20
30
50
75
100
125
150
29
27
26
26
28
27
25
23
21
19
17
27
25
23
21
19
17

F I G. 6. C.

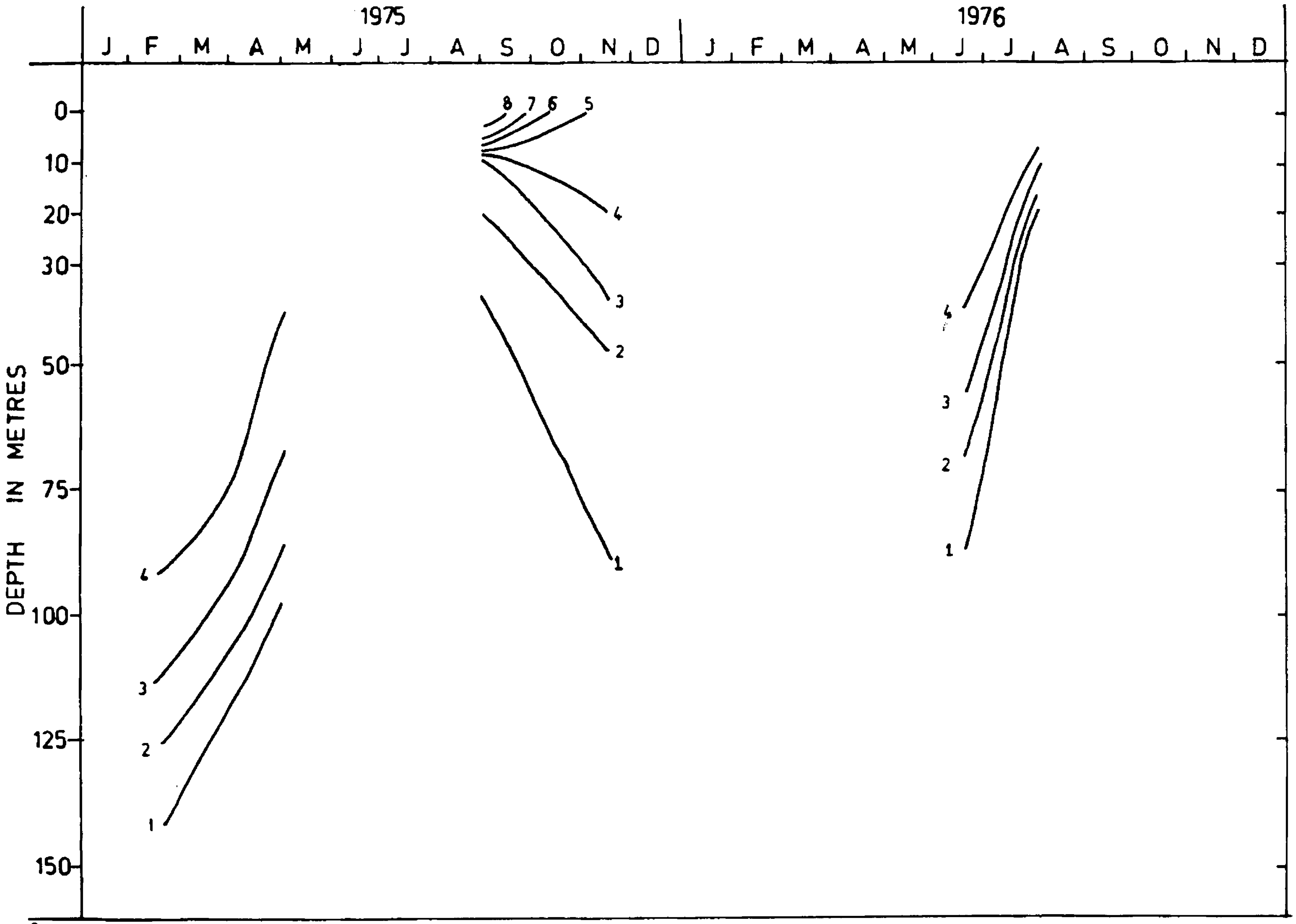
Vertical time section for dissolved oxygen

off Quilon (1973, 1974)


1973
1974
J F M A M J J A S O N D
J F M A M J J A S O N D
DEPTH IN METRES
0
10
30
50
75
100
125
150
6 7
5
4
3
2
1
5
4
3
2
1

F I G. 6. D.

Vertical time section for dissolved oxygen off Quilon (1975, 1976)

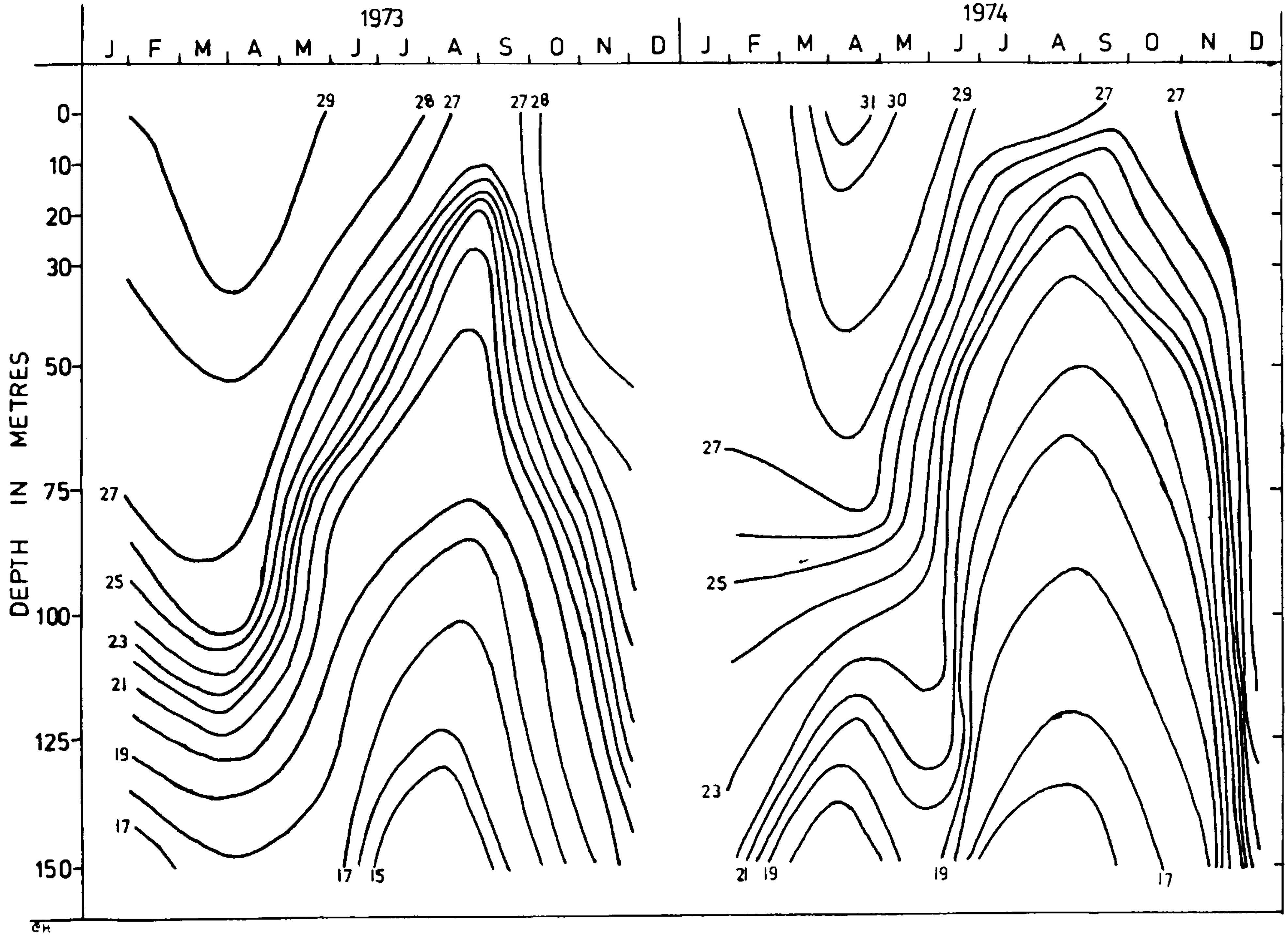


1975
1976
J F M A M J J A S O N D
J F M A M J J A S O N D
DEPTH IN METRES
0
10
20
30
50
75
100
125
150
1
2
3
4
5
6
7
8


a

FIG. 7. A.

Vertical time section for sea water temperature off Cochin (1973, 1974)

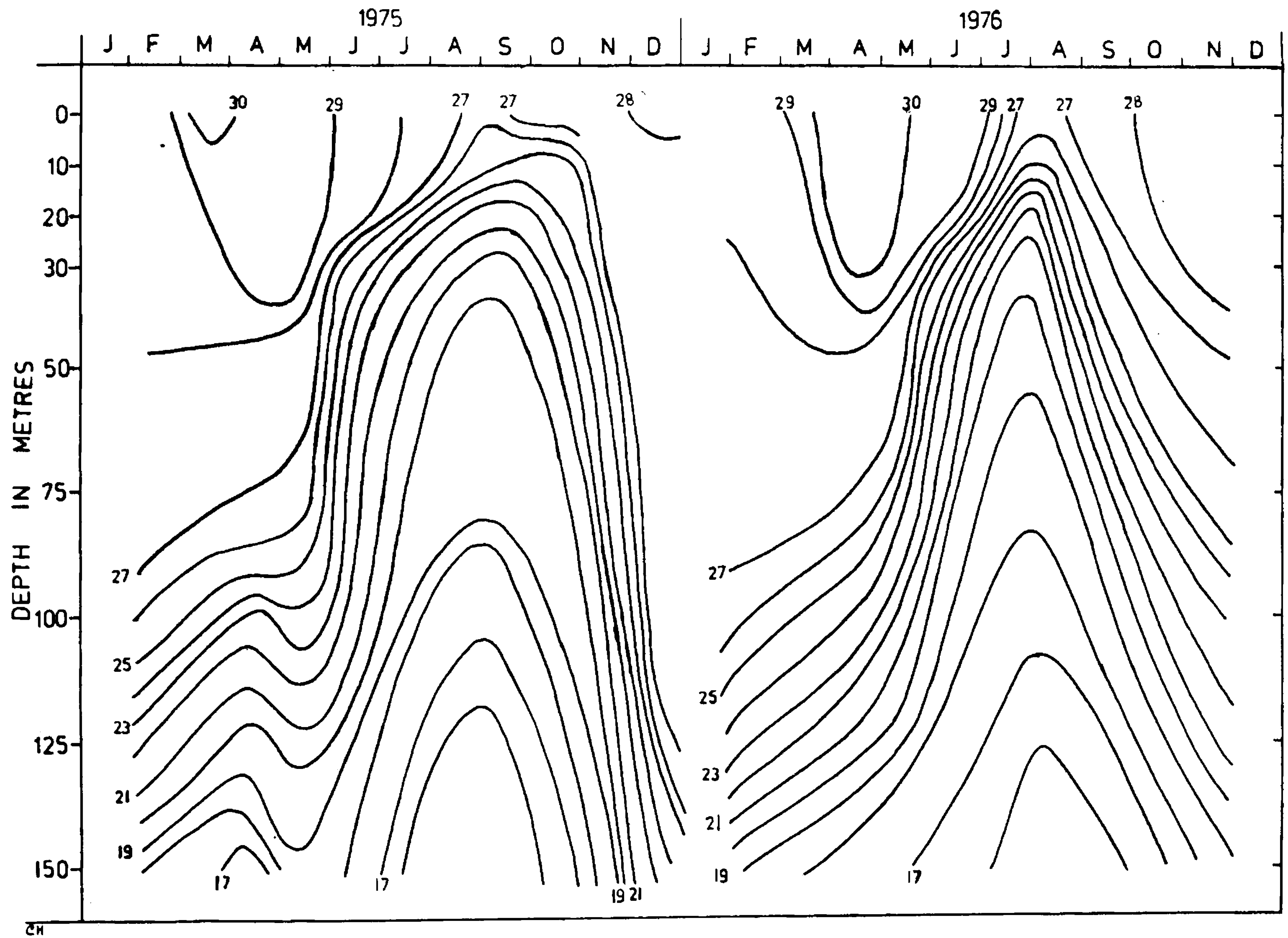


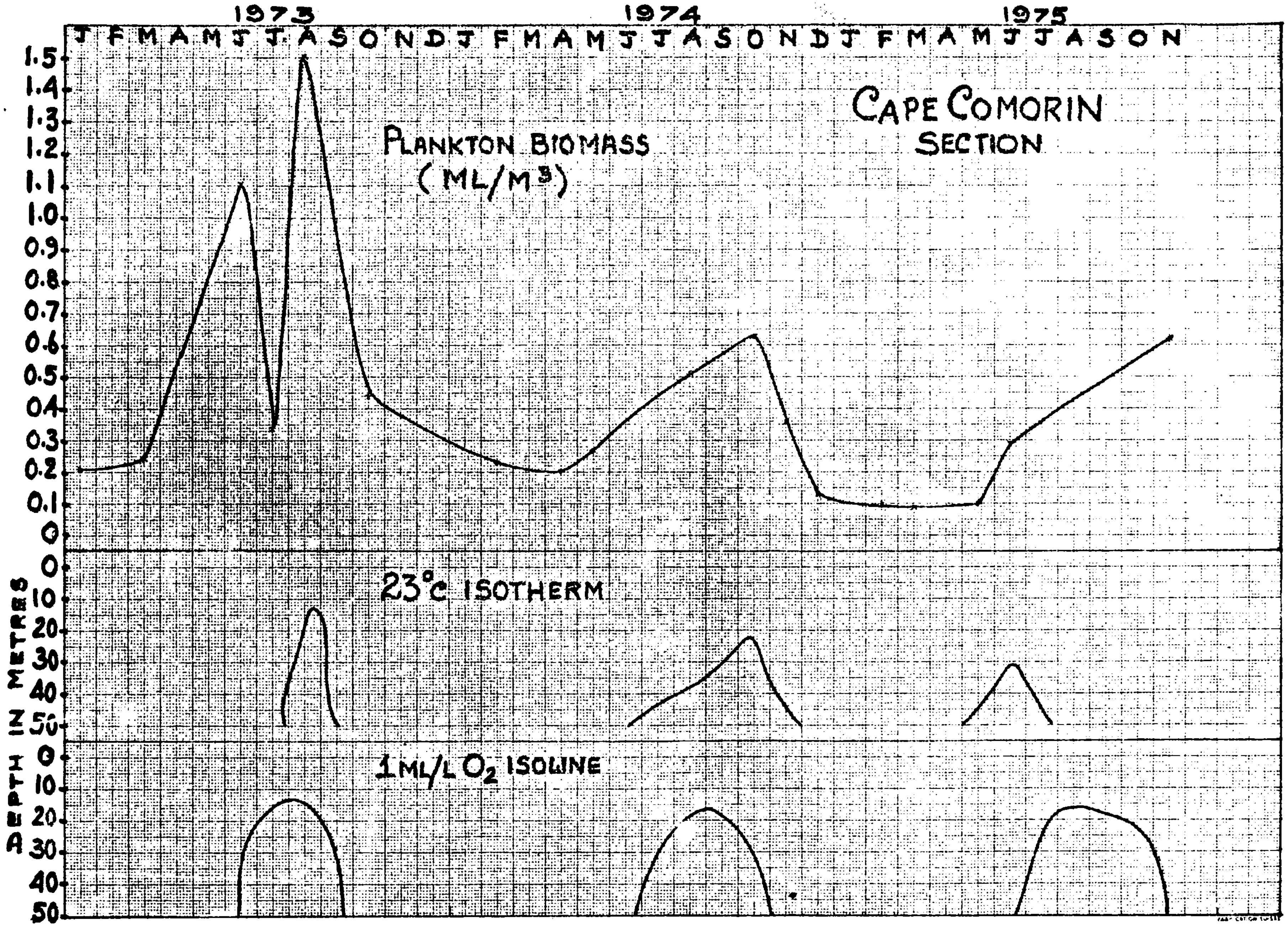
1973
1974
J F M A M J J A S O N D
DEPTH IN METRES
0 10 20 30 50 75 100 125 150
29 28 27 27 28 27 25 23 21 19 17 17 15
31 30 29 27 27 27 25 23 21 19 19 17

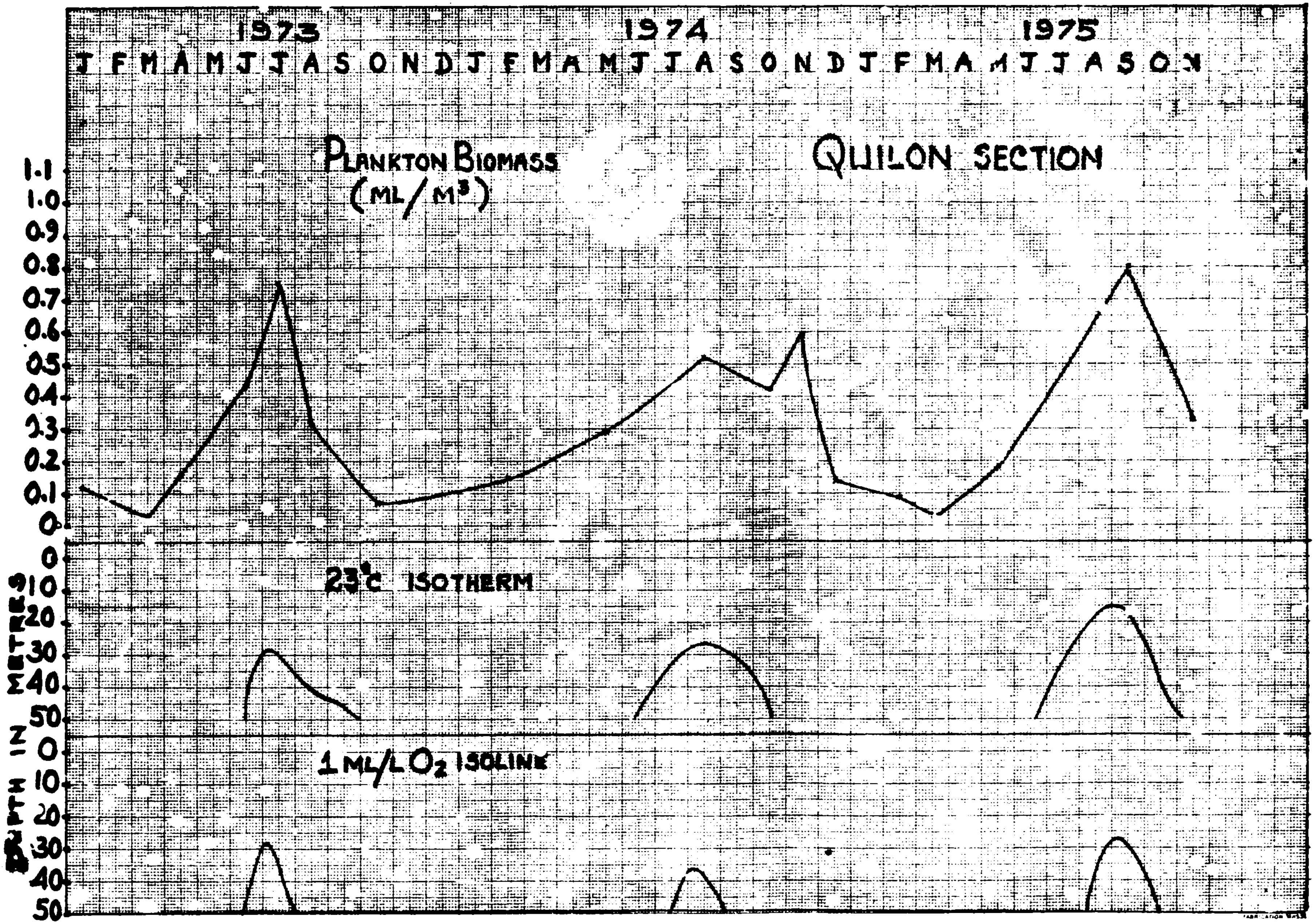
**F I G. 9. B.**

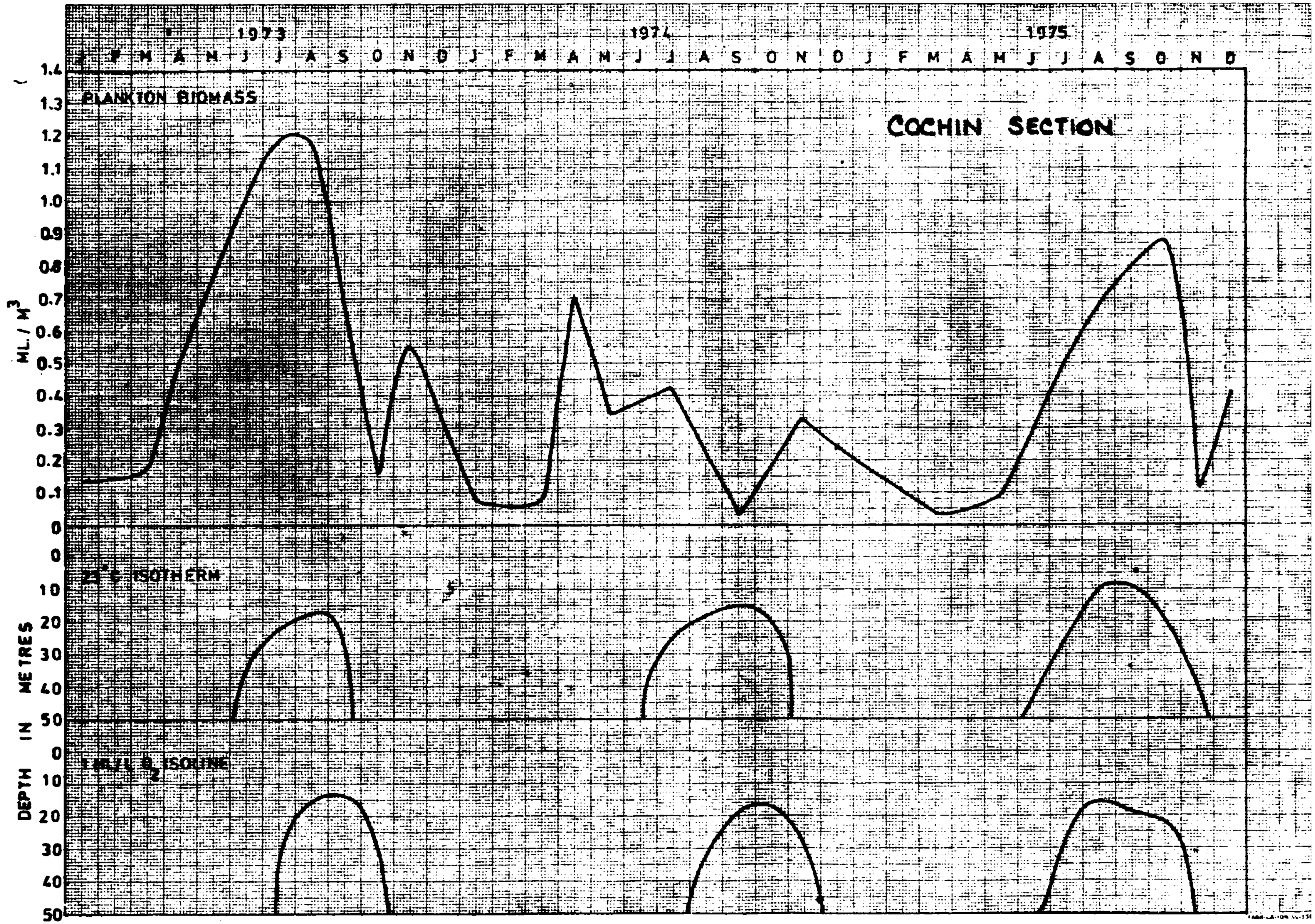
Vertical time section for sea water temperature

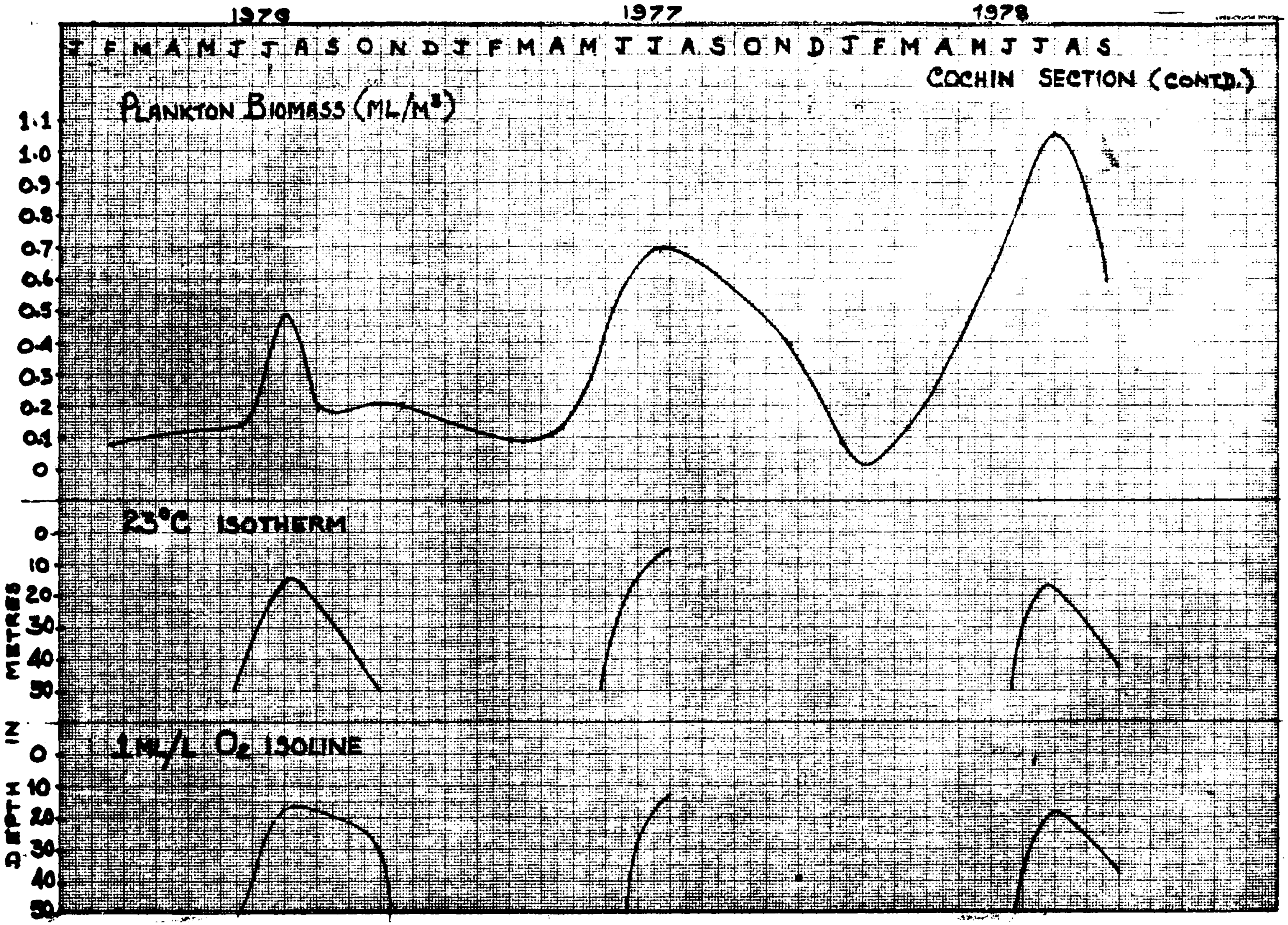
off Cochin (1975, 1976)

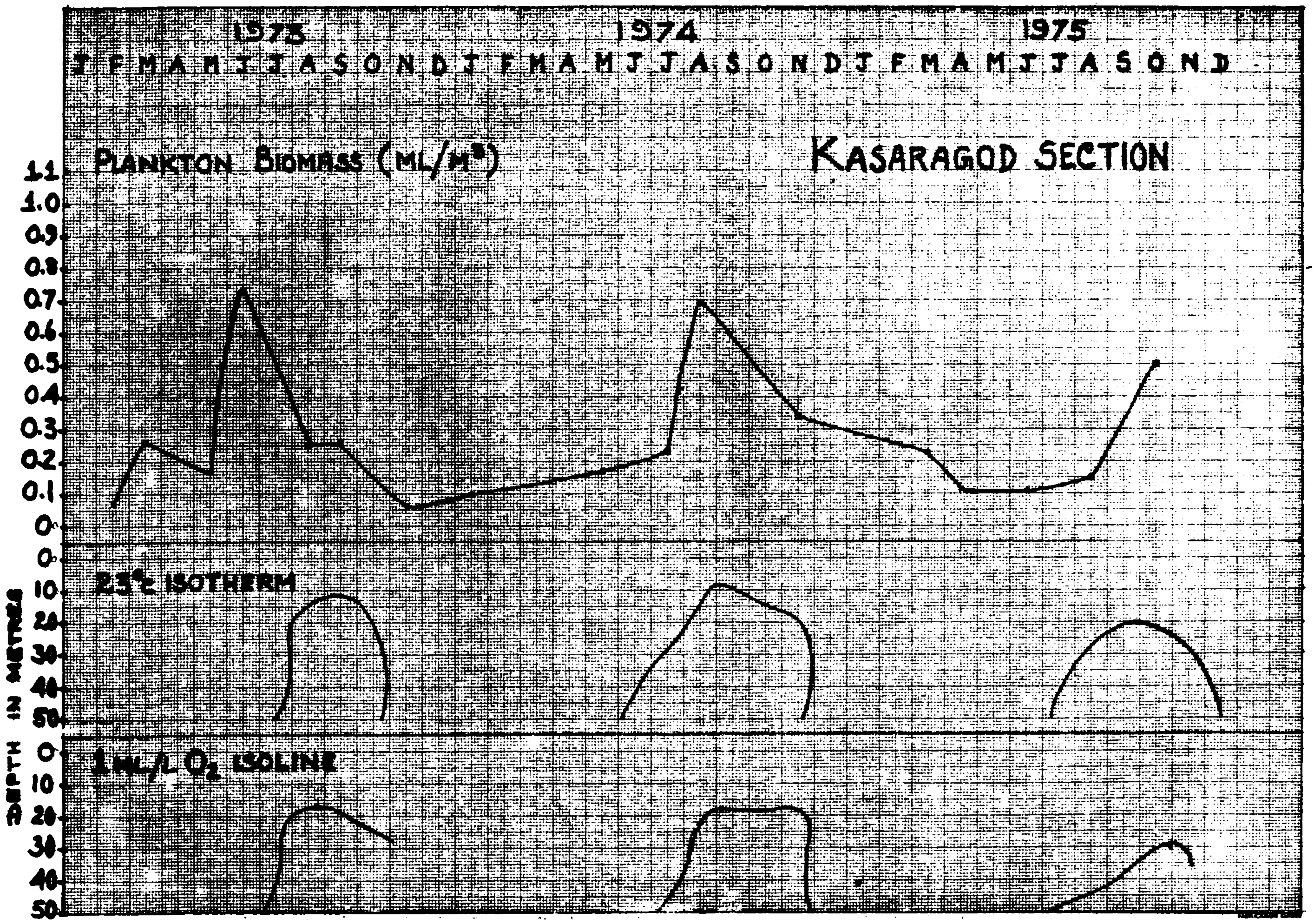

1975
1976
J F M A M J J A S O N D
DEPTH IN METRES
0
10
20
30
50
75
100
125
150
30
29
28
27
25
23
21
19
17

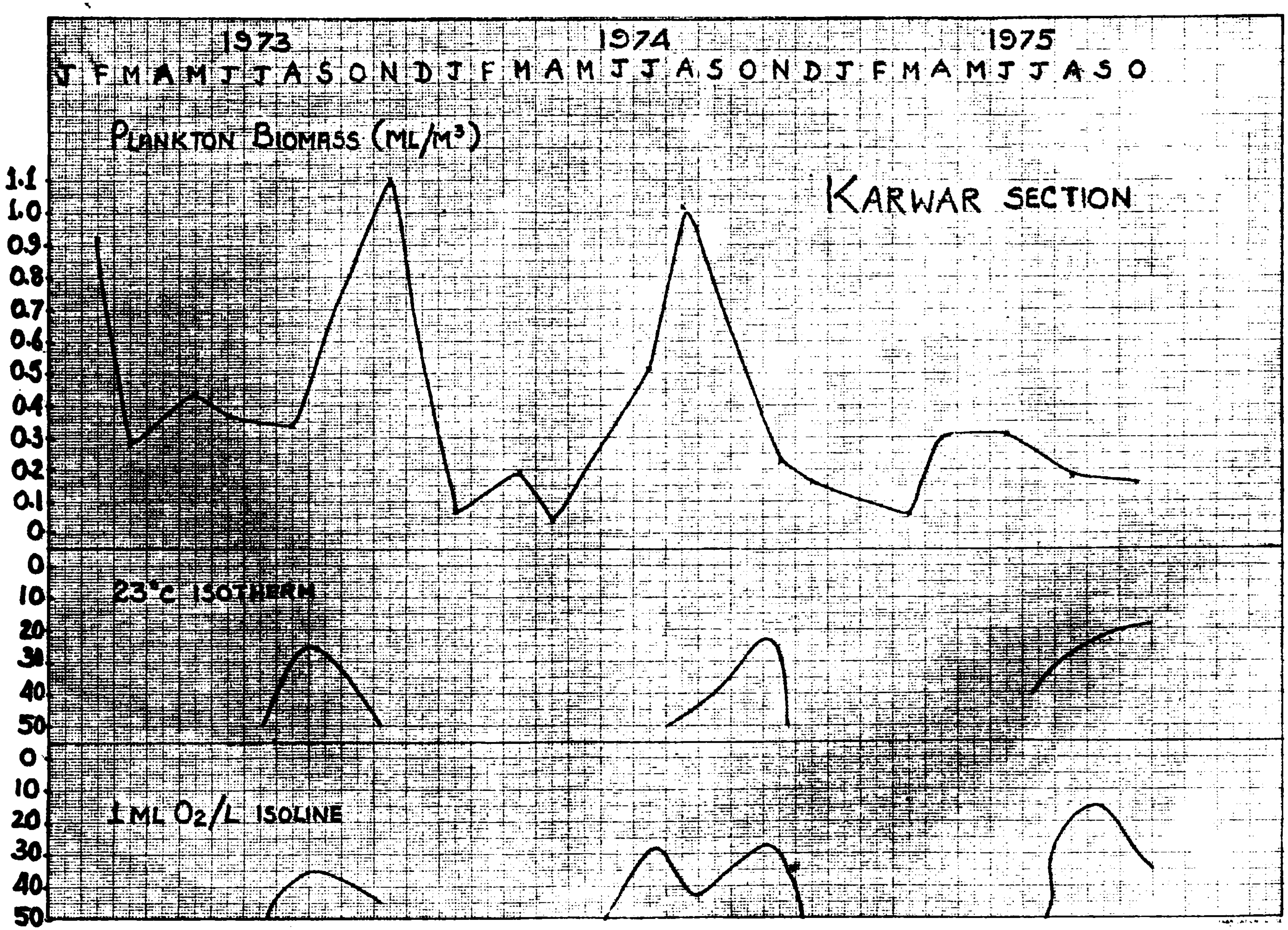

1973
1974
1975
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N
CAPE COMORIN
SECTION
PLANKTON BIOMASS
(ML/M³)
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
23°C ISOTHERM
DEPTH IN METRES
0
10
20
30
40
50
1ML/L O2 ISOLINE
0
10
20
30
40
50

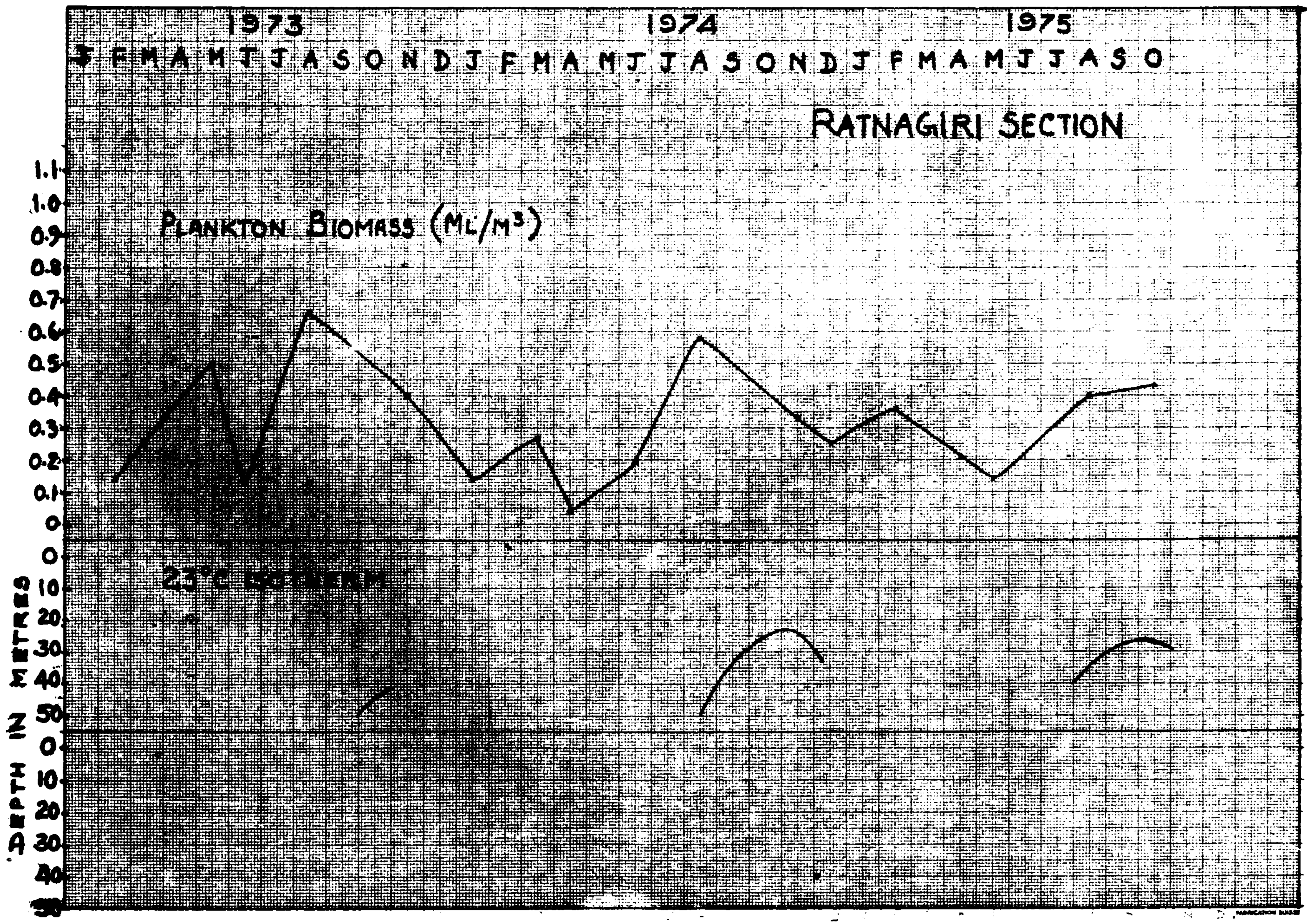

1973
1974
1975
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N
PLANKTON BIOMASS
(ML/M³)
QUILON SECTION
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
23°C ISOTHERM
1 ML/L O2 ISOLINE
DEPTH IN METRES
0
10
20
30
40
50


1973
1974
1975
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
PLANKTON BIOMASS
COCHIN SECTION
ML / M3
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
23°C ISOTHERM
DEPTH IN METRES
0
10
20
30
40
50
1 ML/L O2 ISOLINE
0
10
20
30
40
50


1976
1977
1978
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S
COCHIN SECTION (CONTD.)
PLANKTON BIOMASS (ML/M³)
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
23°C ISOTHERM
0
10
20
30
40
50
DEPTH IN METRES
1 ML/L O2 ISOLINE
0
10
20
30
40
50


1973
1974
1975
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
PLANKTON BIOMASS (ML/M³)
KASARAGOD SECTION
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
25°C ISOTHERM
1 ML/L O₂ ISOLINE
DEPTH IN METRES
0
10
20
30
40
50

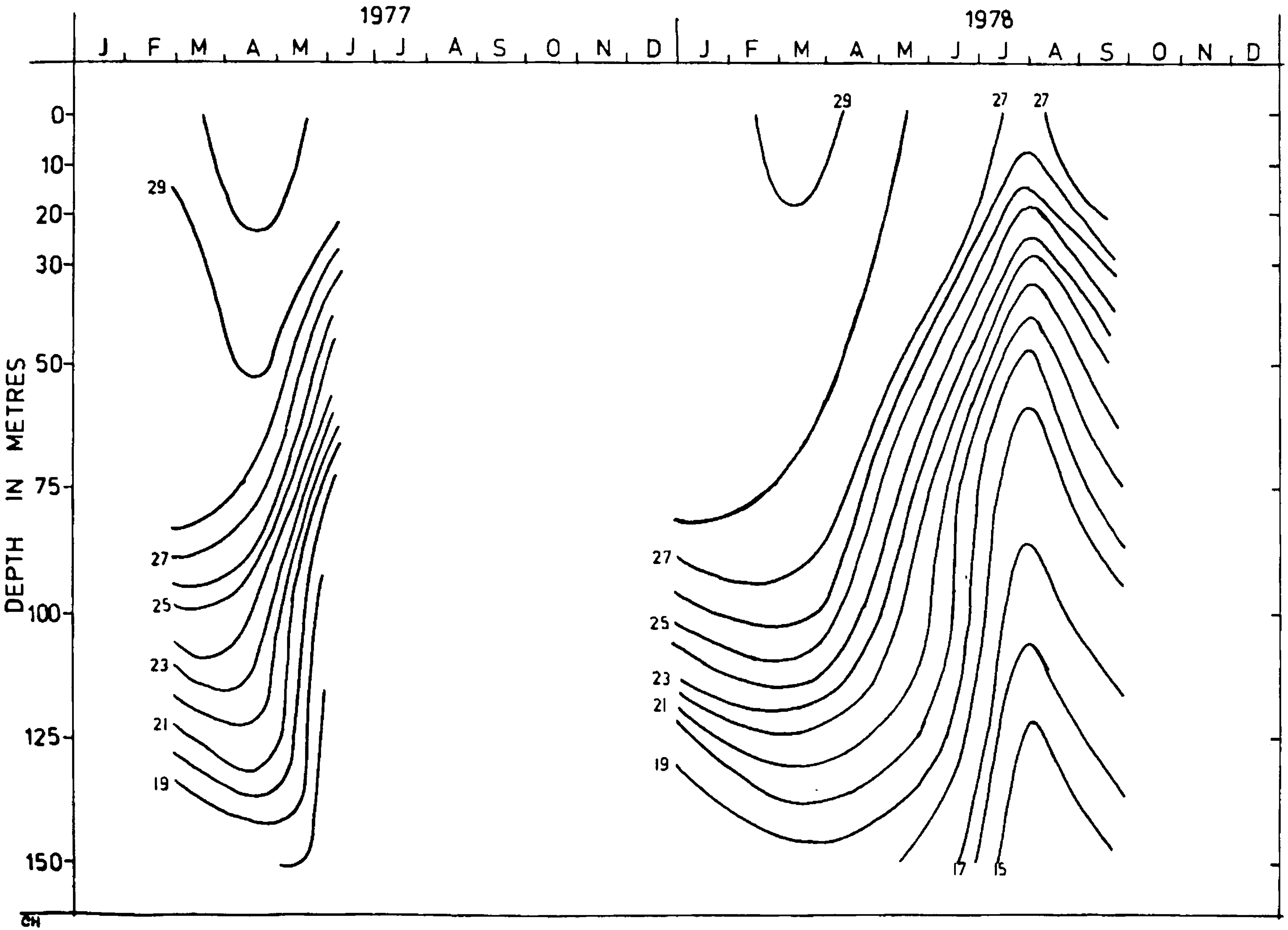

1973
1974
1975
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O
PLANKTON BIOMASS (ML/M³)
KARWAR SECTION
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
23°C ISOTHERM
0
10
20
30
40
50
1 ML O2/L ISOLINE



1973
1974
1975
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O
RATNAGIRI SECTION
PLANKTON BIOMASS (ML/M³)
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
23°C ISOTHERM
DEPTH IN METRES
0
10
20
30
40
50
0
10
20
30
40

F I G. 7. C.

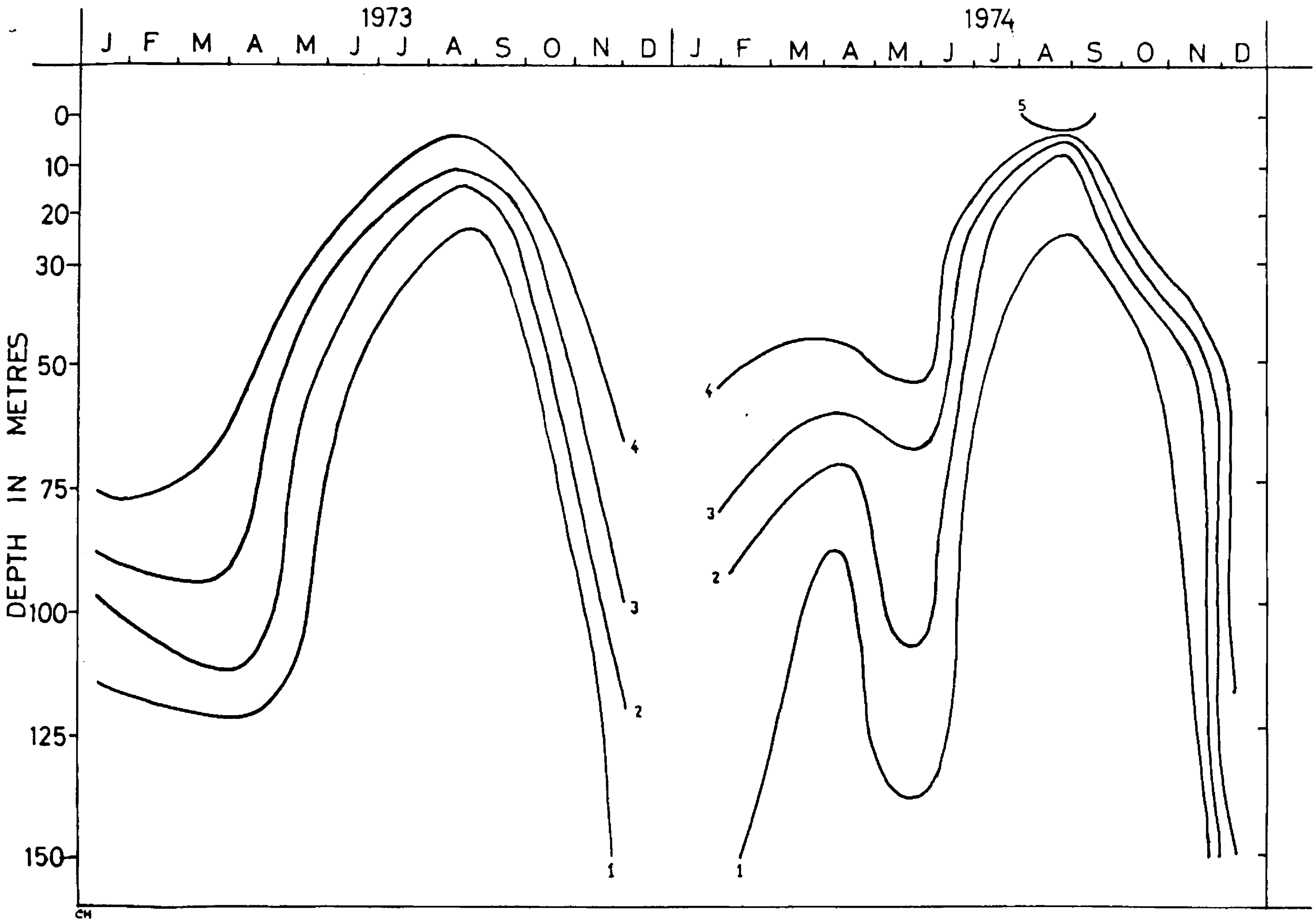
Vertical time section for sea water temperature off Cochin (1977, 1978)



1977
1978
J F M A M J J A S O N D
J F M A M J J A S O N D
DEPTH IN METRES
0
10
20
30
50
75
100
125
150
29
27
25
23
21
19
17
15
CH

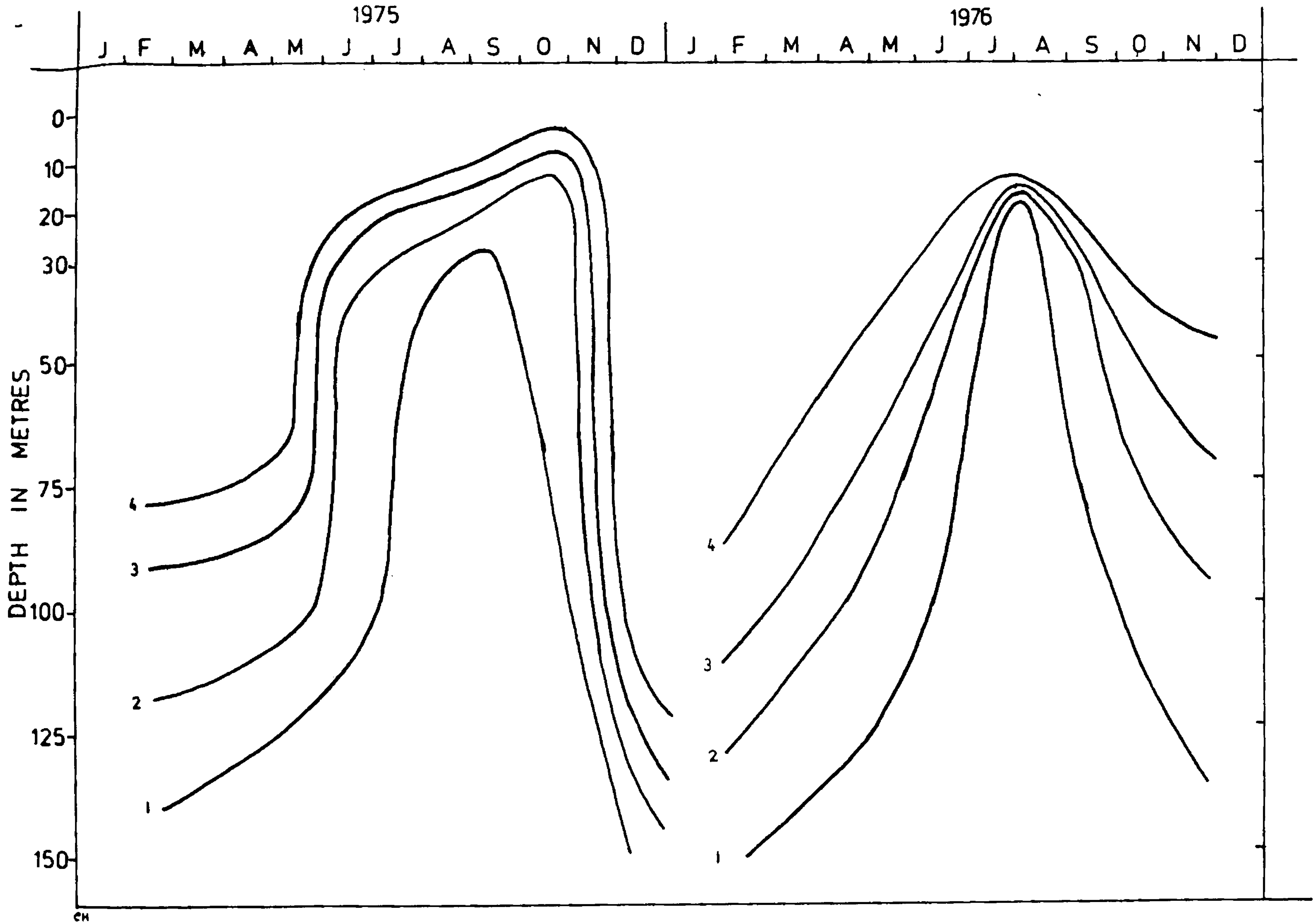
F I G. 7. D.

Vertical time section for dissolved oxygen off Cochin (1973, 1974)


1973
1974
J F M A M J J A S O N D
J F M A M J J A S O N D
DEPTH IN METRES
0
10
20
30
50
75
100
125
150
1
2
3
4
5
CH

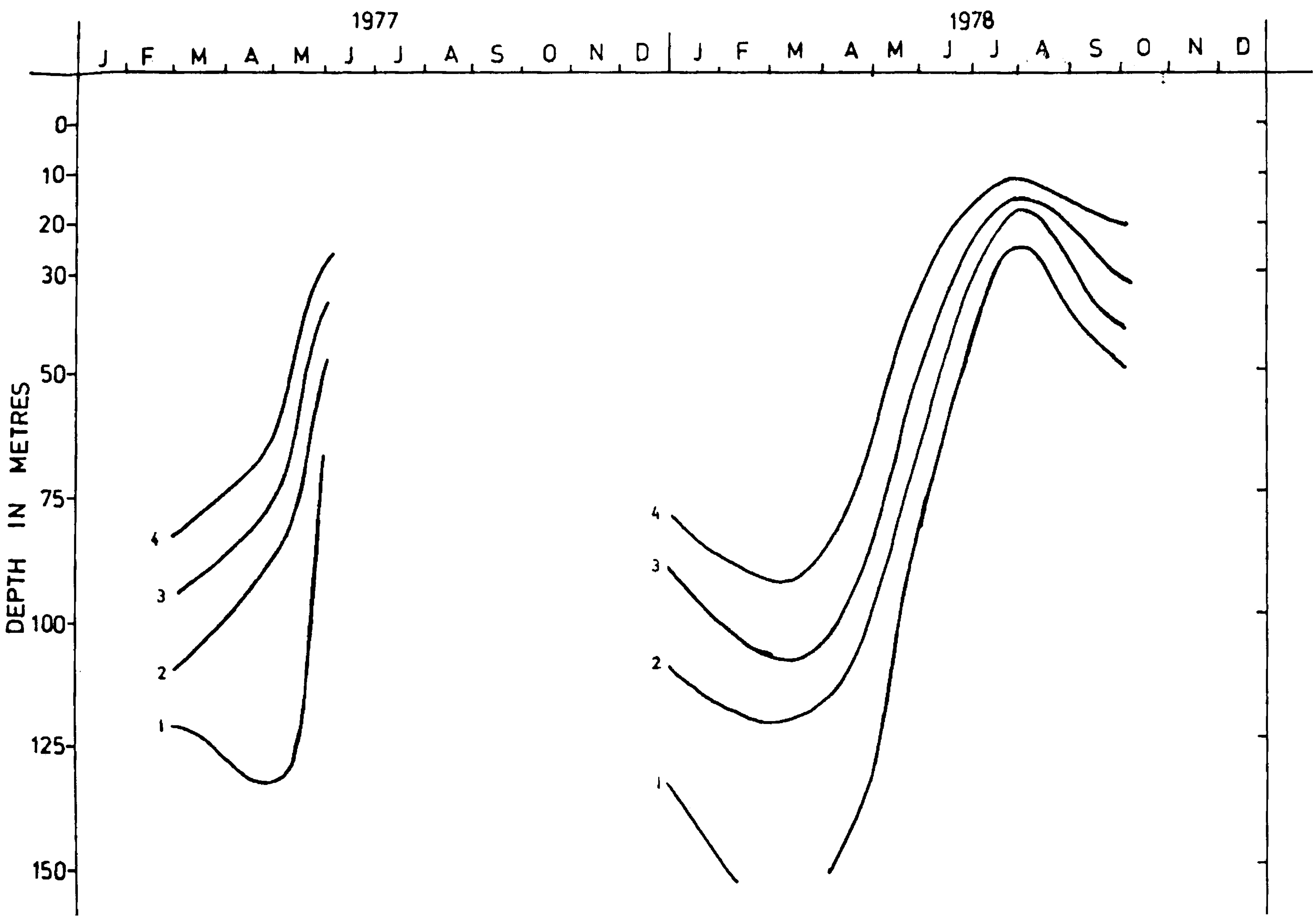
F I G. 7. E

Vertical time section for dissolved oxygen off Cochin (1975, 1976)


1975
1976
J F M A M J J A S O N D J F M A M J J A S O N D
DEPTH IN METRES
0
10
20
30
50
75
100
125
150
1
2
3
4
CM

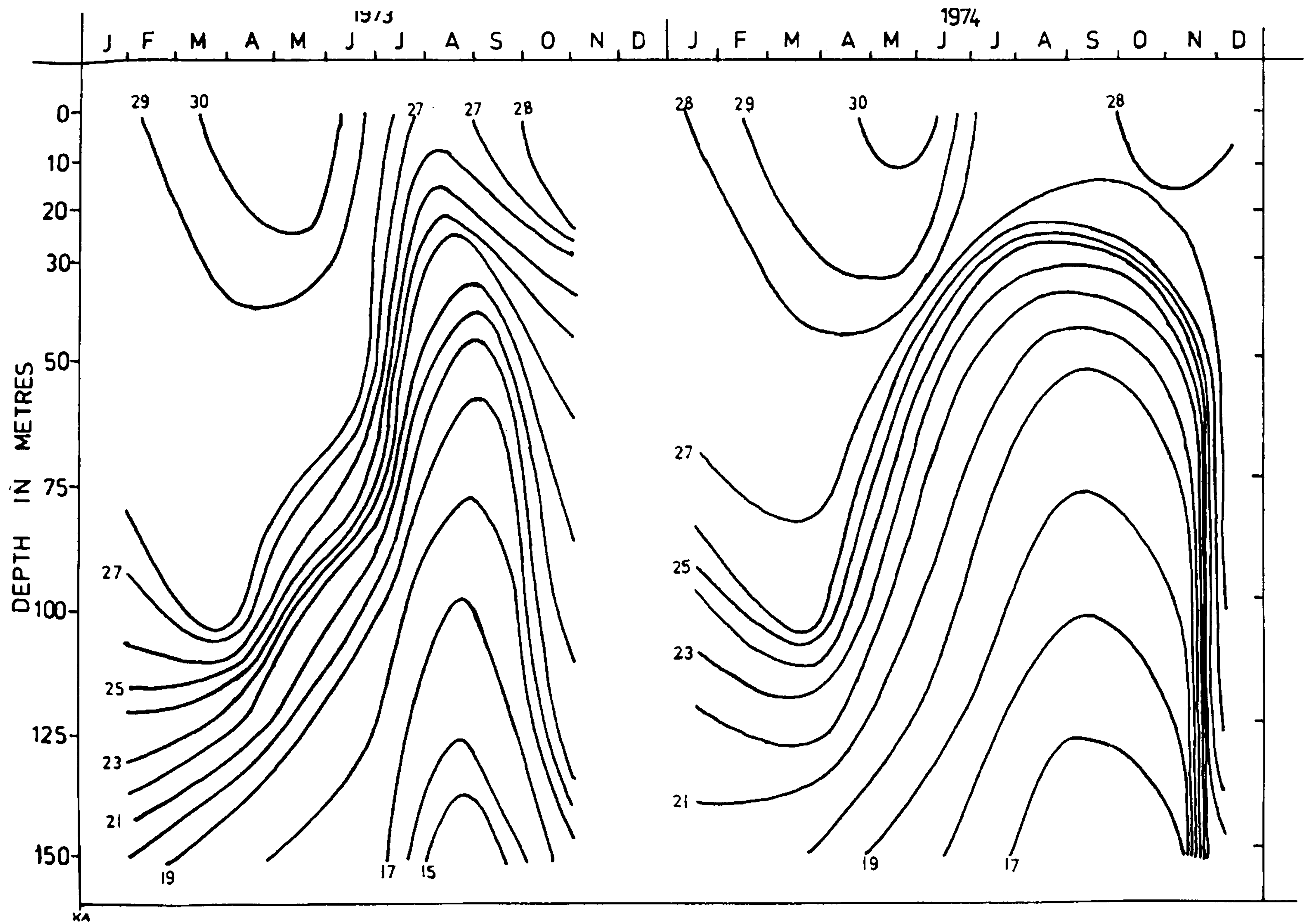
F I G. 7. F.

Vertical time section for dissolved oxygen off Cochin (1977, 1978)


1977
1978
J F M A M J J A S O N D
J F M A M J J A S O N D
DEPTH IN METRES
0
10
20
30
50
75
100
125
150
1
2
3
4
1
2
3
4

F I G. 8. A.

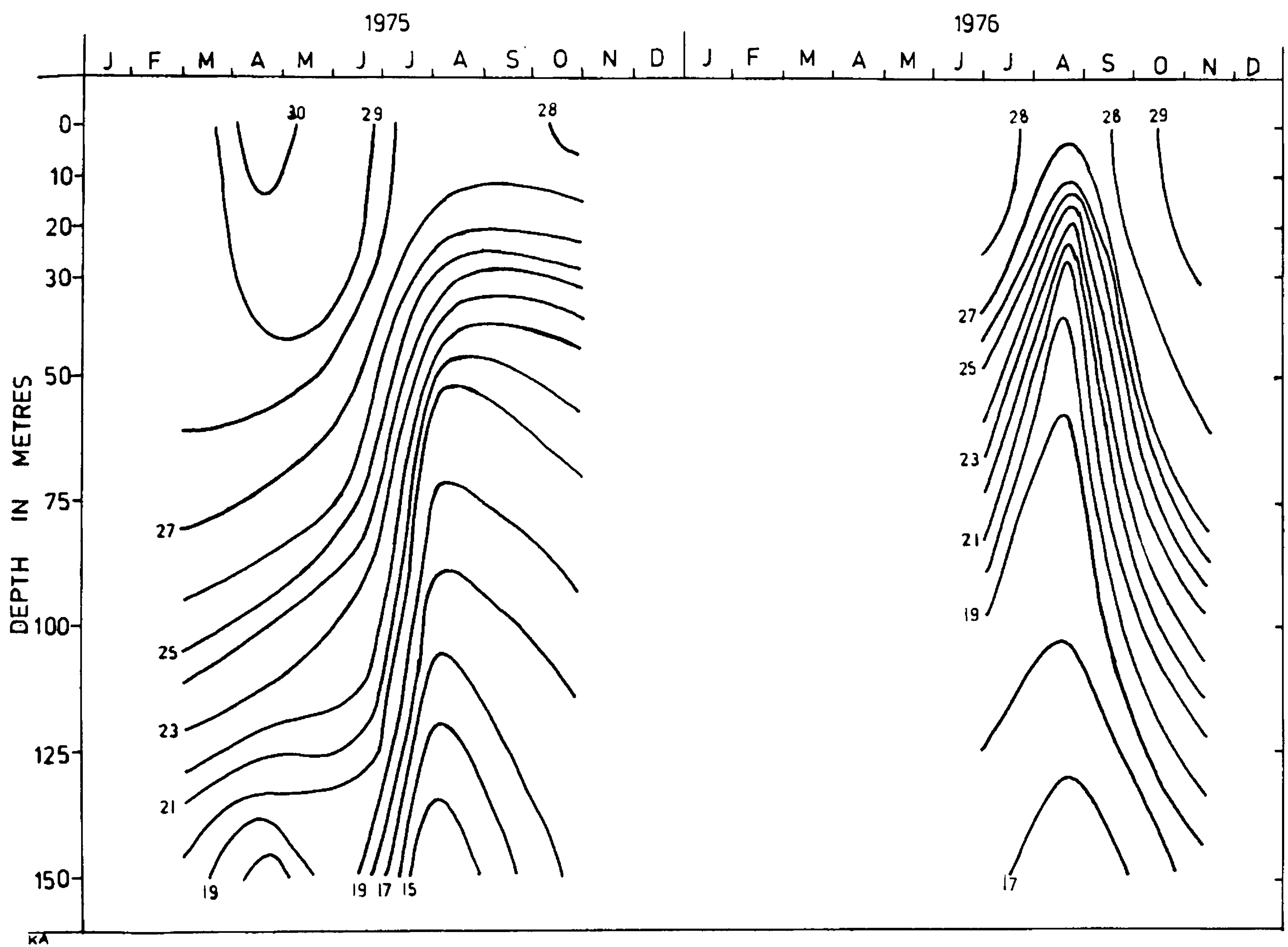
Vertical time section for sea water temperature off Kasaragod (1973, 1974)


1973
1974
J F M A M J J A S O N D
J F M A M J J A S O N D
DEPTH IN METRES
0
10
20
30
50
75
100
125
150
29
30
27
27
28
27
25
23
21
19
17
15
28
29
30
28
27
25
23
21
19
17
KA

F I G. 8. B

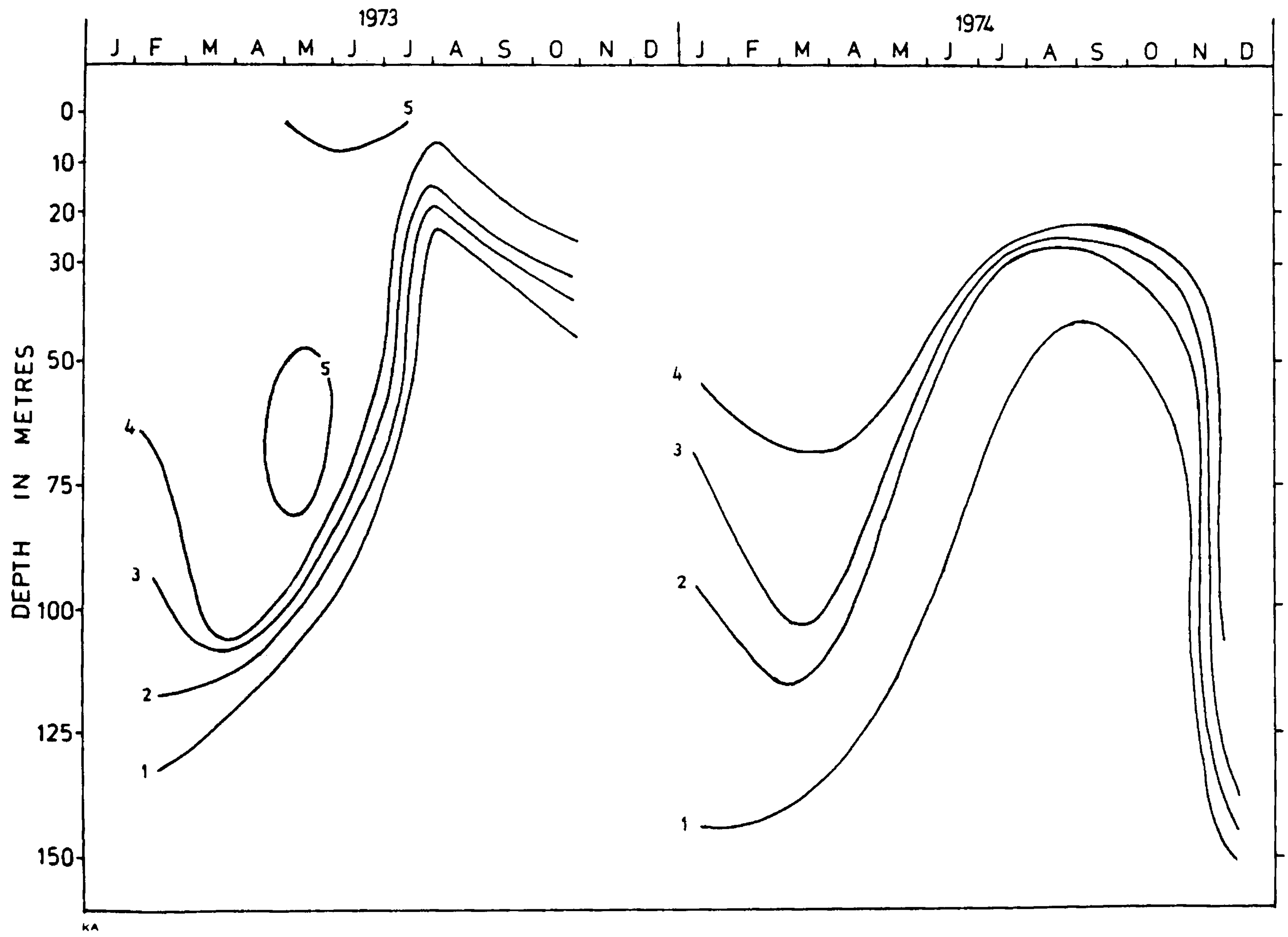
Vertical time section for sea water temperature

off Kasaragod (1975, 1976)


1975
1976
J F M A M J J A S O N D
J F M A M J J A S O N D
DEPTH IN METRES
0
10
20
30
50
75
100
125
150
30
29
28
27
25
23
21
19
19 17 15
28
28
29
27
25
23
21
19
17
KA

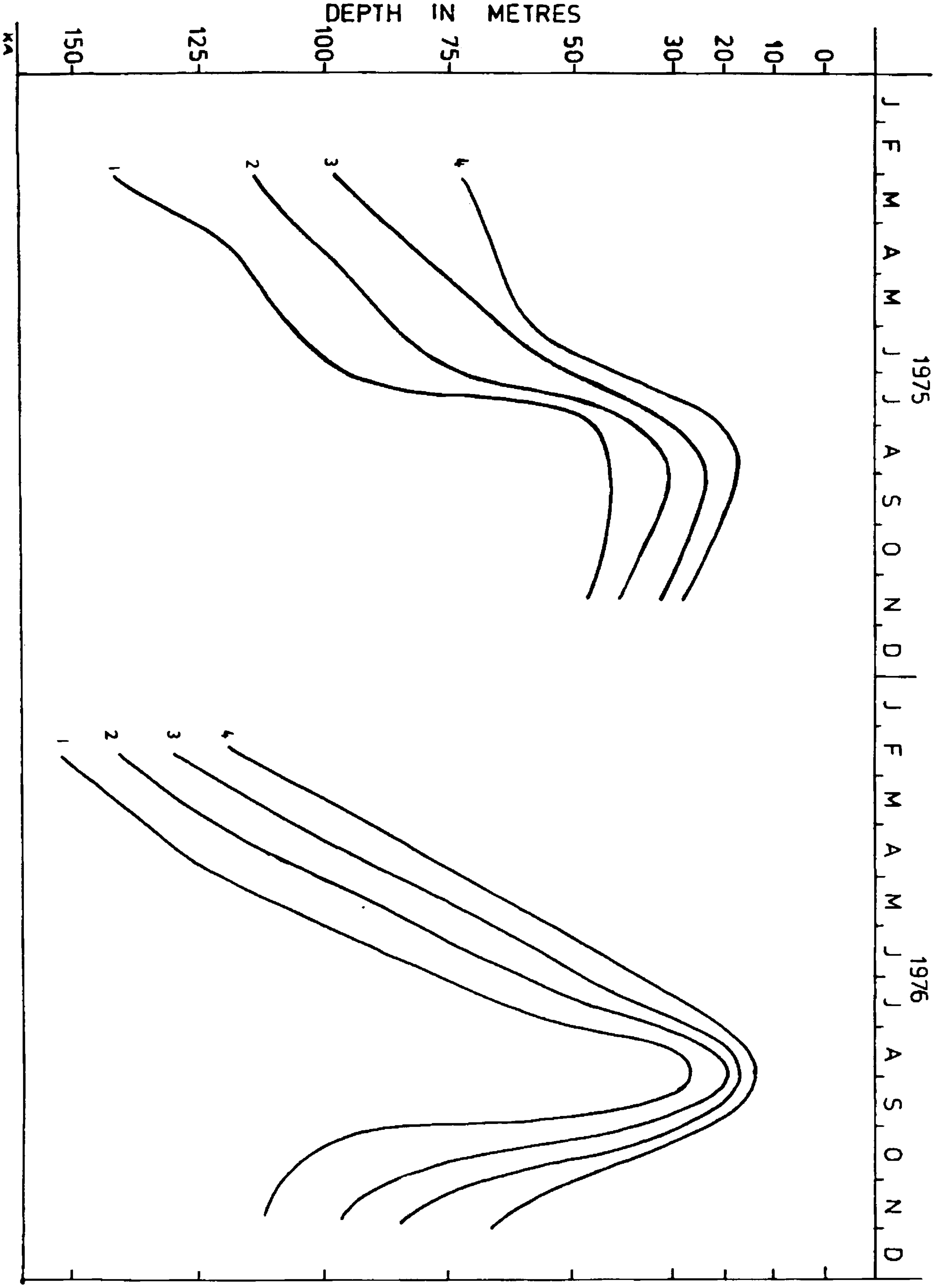
F I G. 8. C.

Vertical time section for dissolved oxygen off Kasaragod (1973, 1974)


1973
1974
J F M A M J J A S O N D
J F M A M J J A S O N D
DEPTH IN METRES
0
10
20
30
50
75
100
125
150
1
2
3
4
5
5
1
2
3
4
KA

F I G. 8. D.

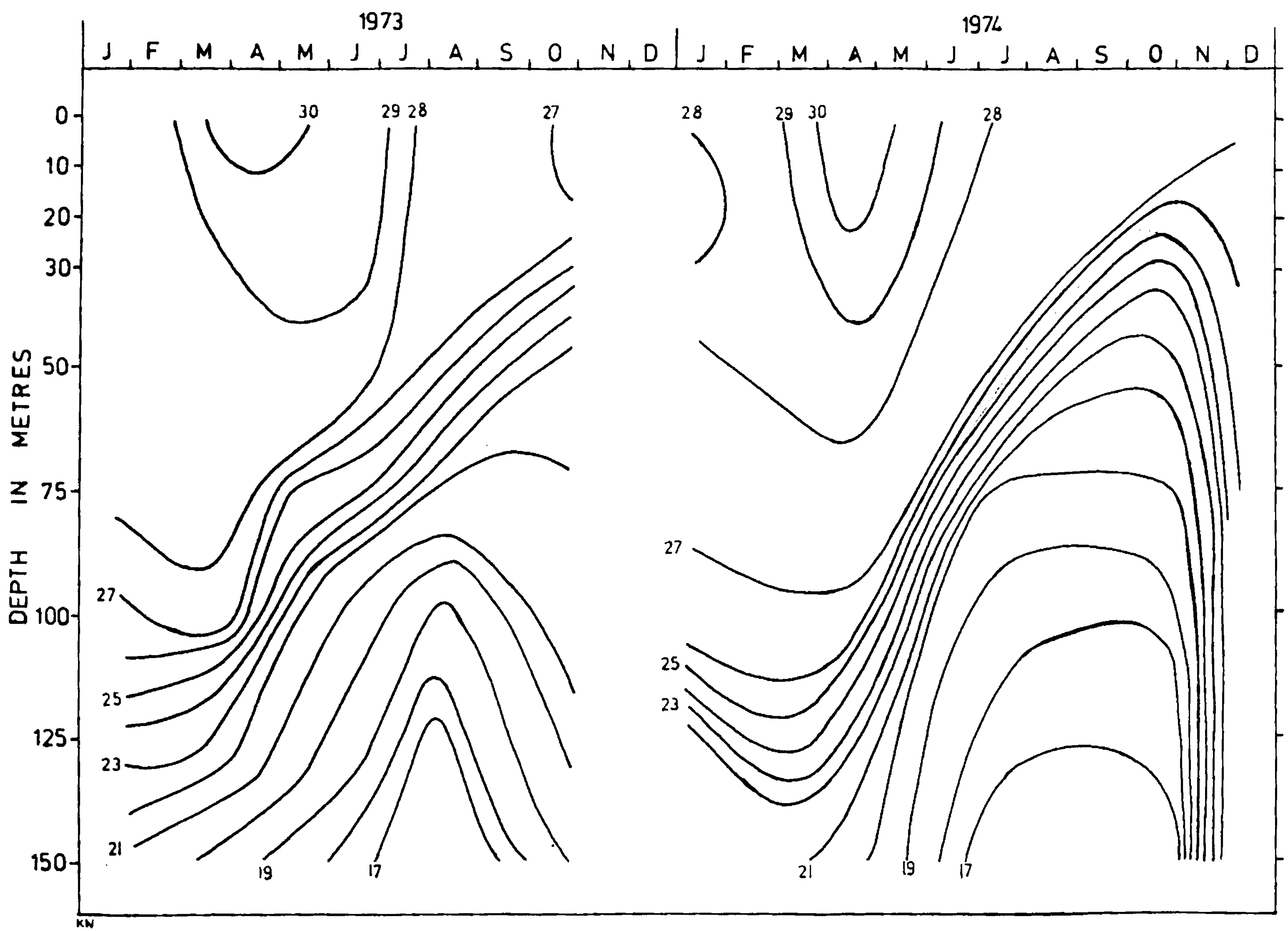
Vertical time section for dissolved oxygen off Kasaragod (1975, 1976)



DEPTH IN METRES
0
10
20
30
50
75
100
125
150
J F M A M J J A S O N D
1975
J F M A M J J A S O N D
1976
1
2
3
4
1
2
3
4

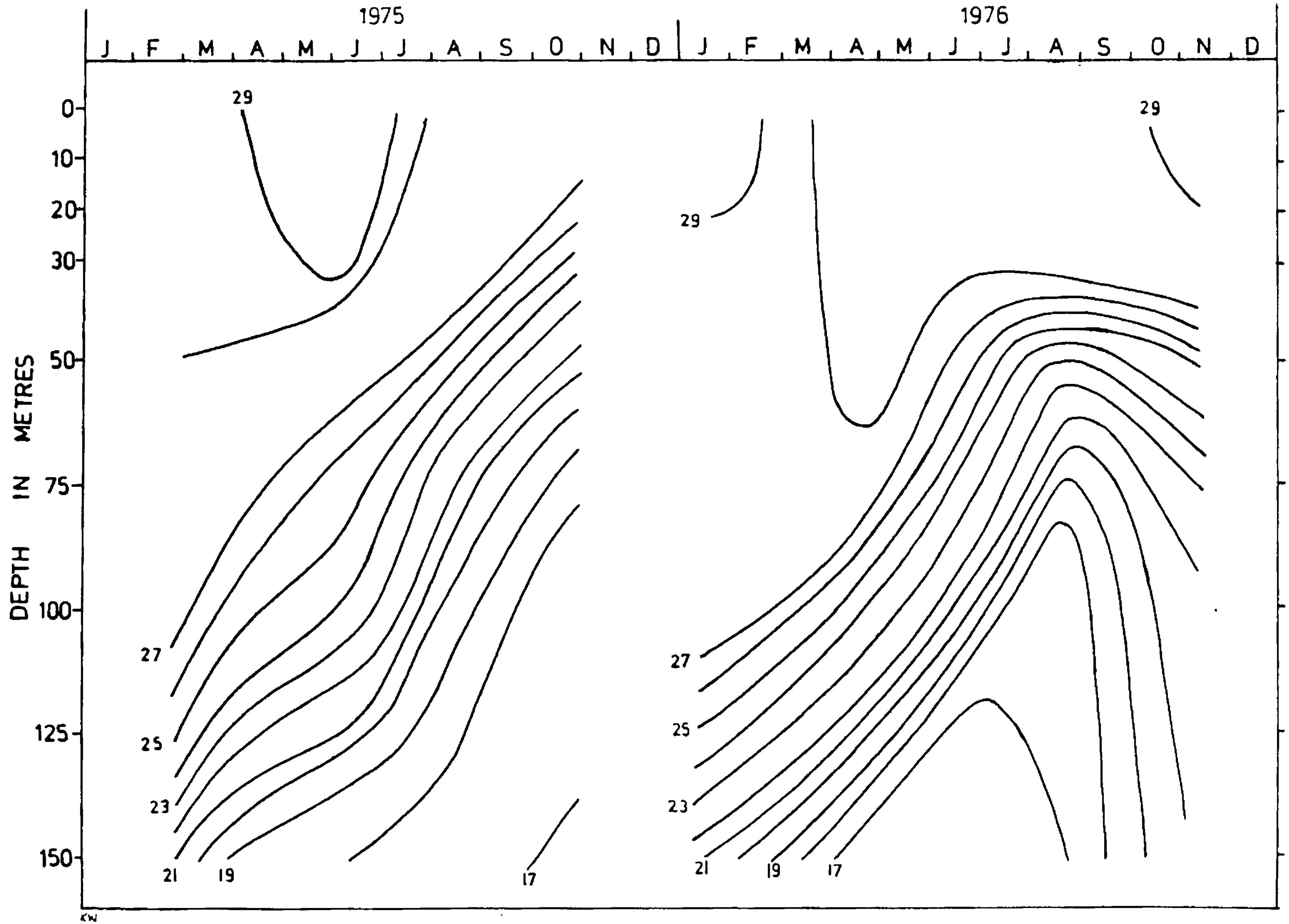
F I G. 9. A.

Vertical time section for sea water temperature off Karwar (1973, 1974)


1973
1974
J F M A M J J A S O N D J F M A M J J A S O N D
DEPTH IN METRES
0
10
20
30
50
75
100
125
150
30
29 28
27
28
29 30
28
27
25
23
21
19
17
KN

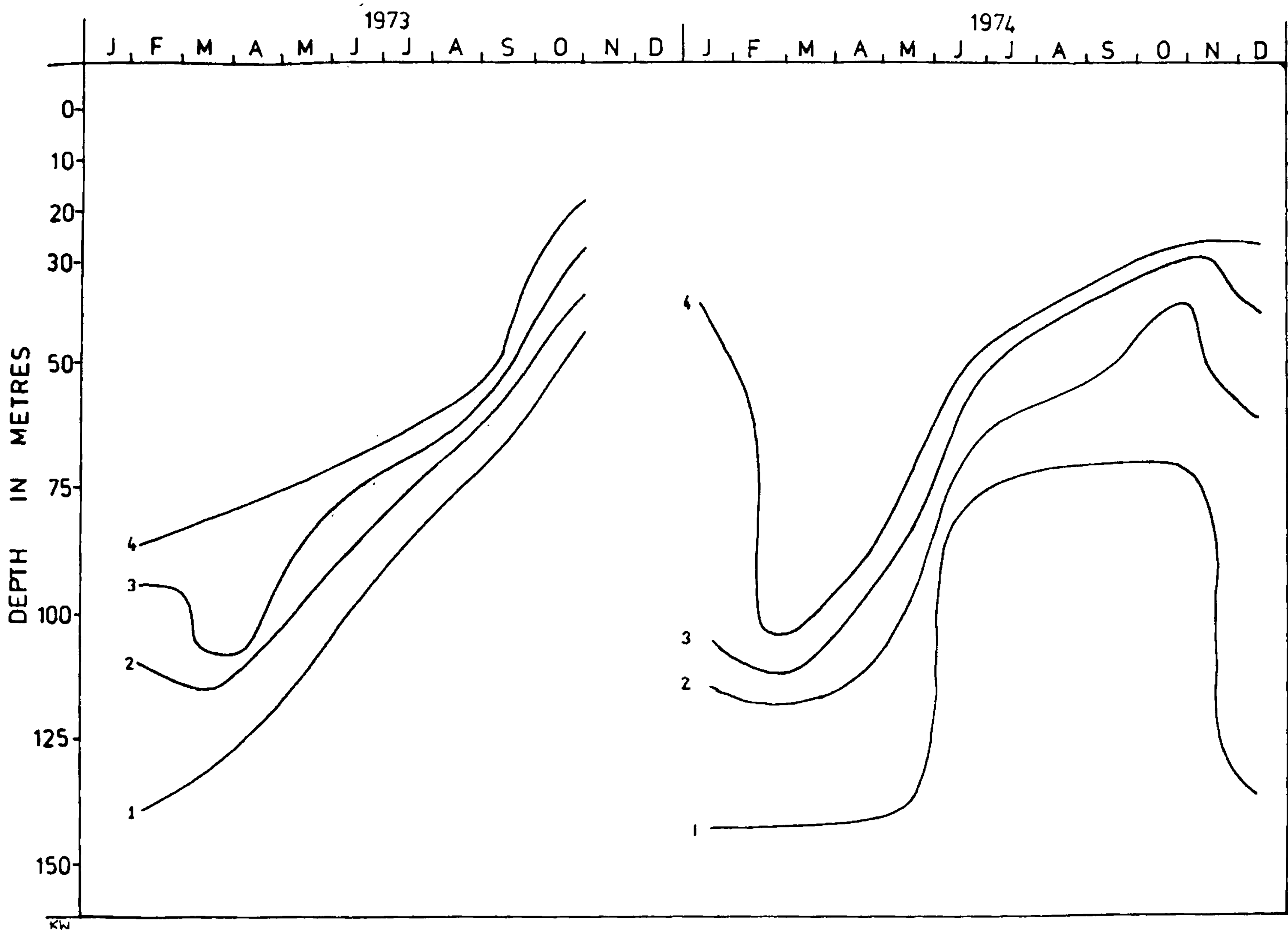
F I G. 9. B.

Vertical time section for sea water temperature off Karwar (1975, 1976)


1975
1976
J F M A M J J A S O N D
J F M A M J J A S O N D
DEPTH IN METRES
0
10
20
30
50
75
100
125
150
29
27
25
23
21
19
17

F I G. 9. C.

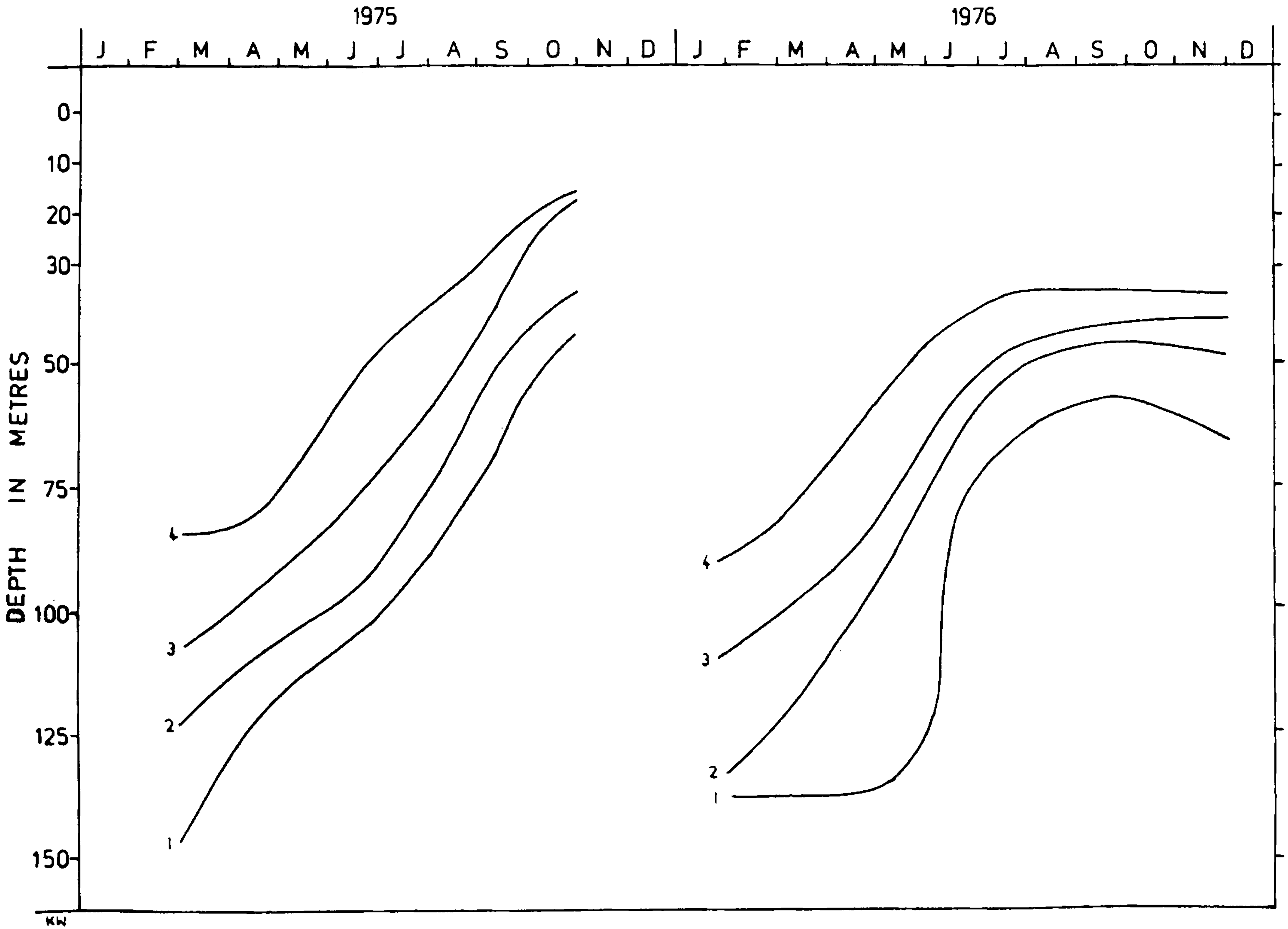
Vertical time section for dissolved oxygen off Karwar (1973, 1974)



1973
1974
J F M A M J J A S O N D
J F M A M J J A S O N D
DEPTH IN METRES
0
10
20
30
50
75
100
125
150
1
2
3
4
KW

F I G. 9. D.

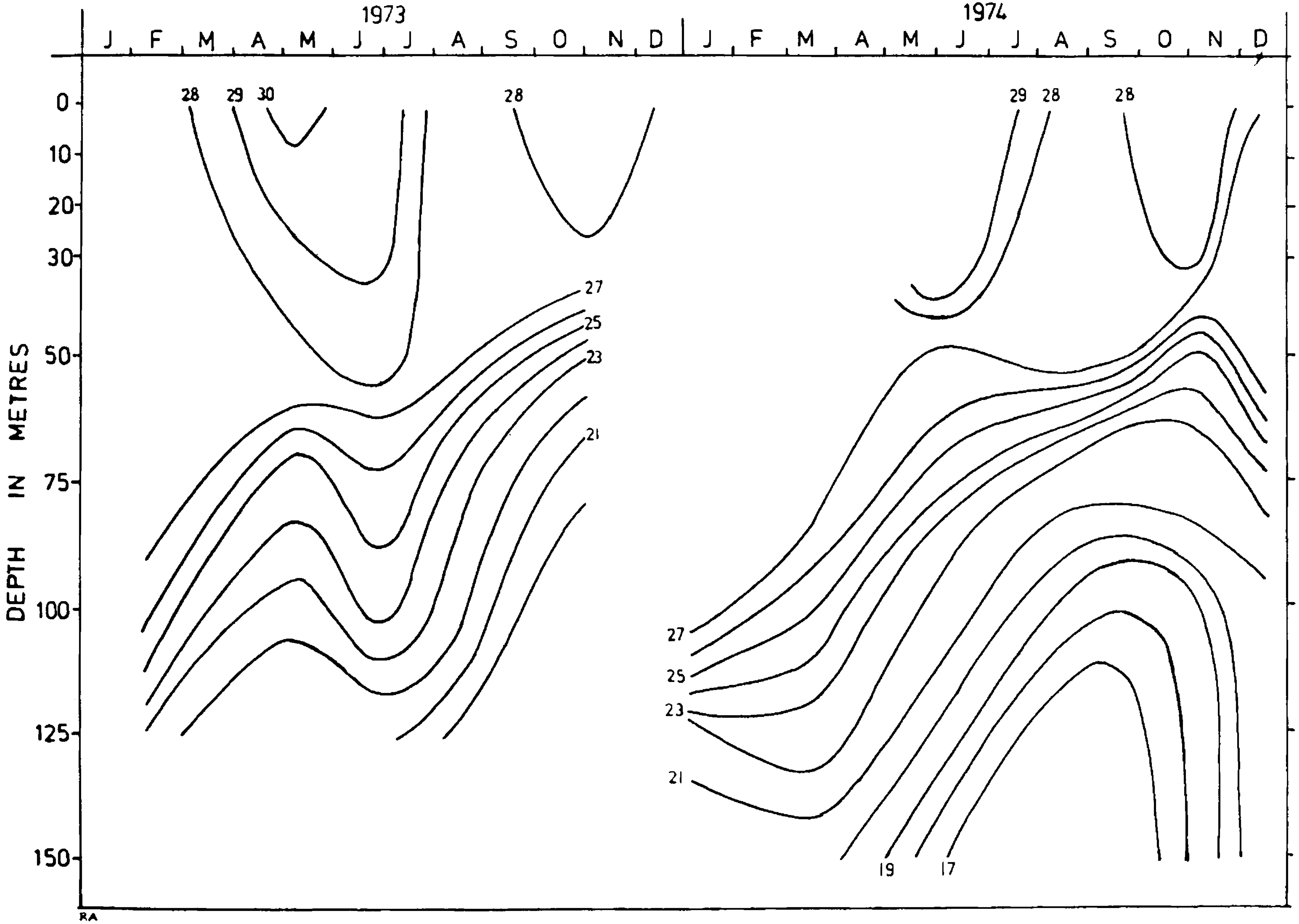
Vertical time section for dissolved oxygen off Karwar (1975, 1976)



1975
1976
J F M A M J J A S O N D
J F M A M J J A S O N D
DEPTH IN METRES
0
10
20
30
50
75
100
125
150
1
2
3
4
KW

F I G. 10. A

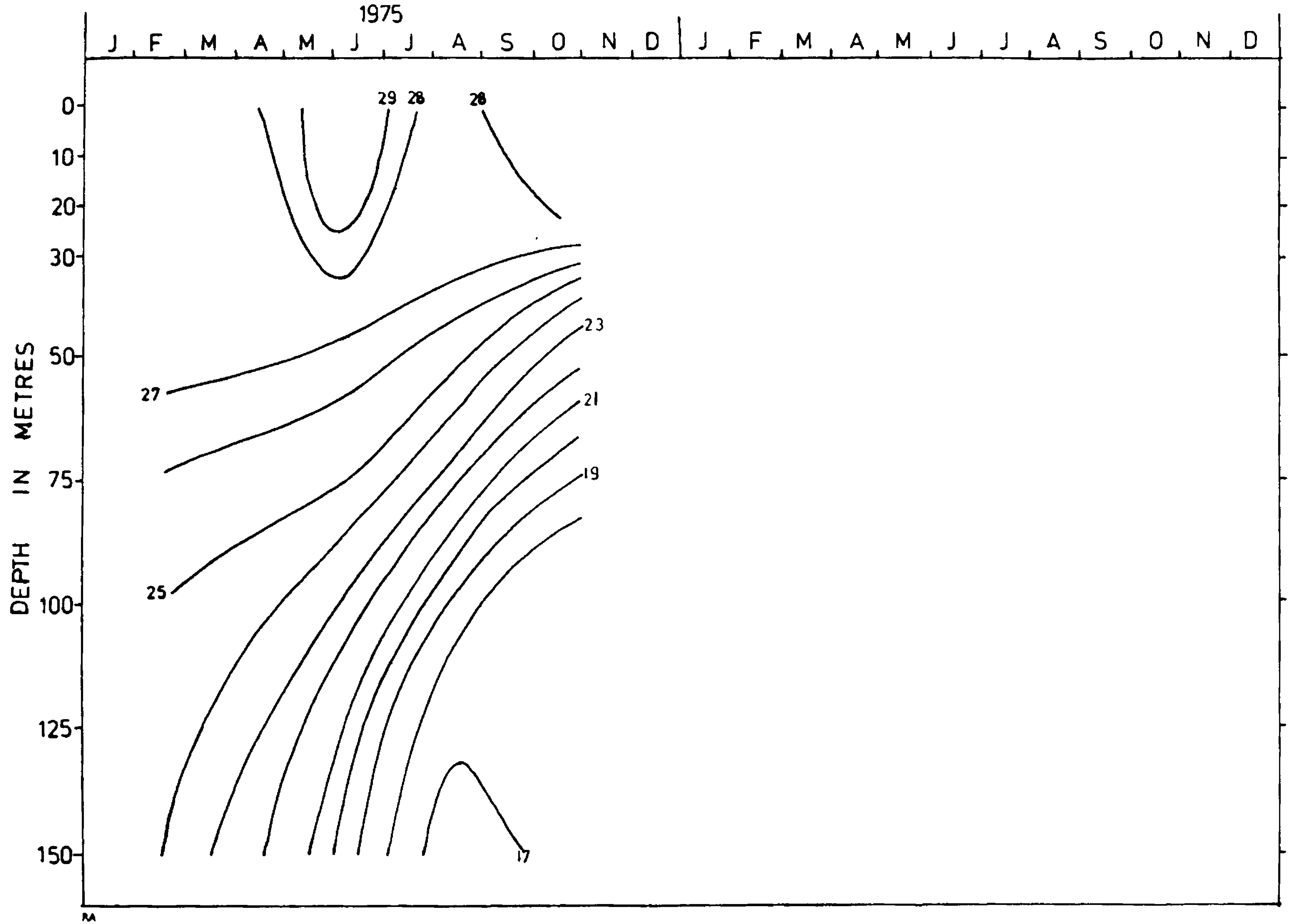
Vertical time section for sea water temperature off Ratnagiri (1973, 1974)



1973
1974
J F M A M J J A S O N D
J F M A M J J A S O N D
DEPTH IN METRES
0
10
20
30
50
75
100
125
150
28
29
30
28
27
25
23
21
29
28
28
27
25
23
21
19
17
RA

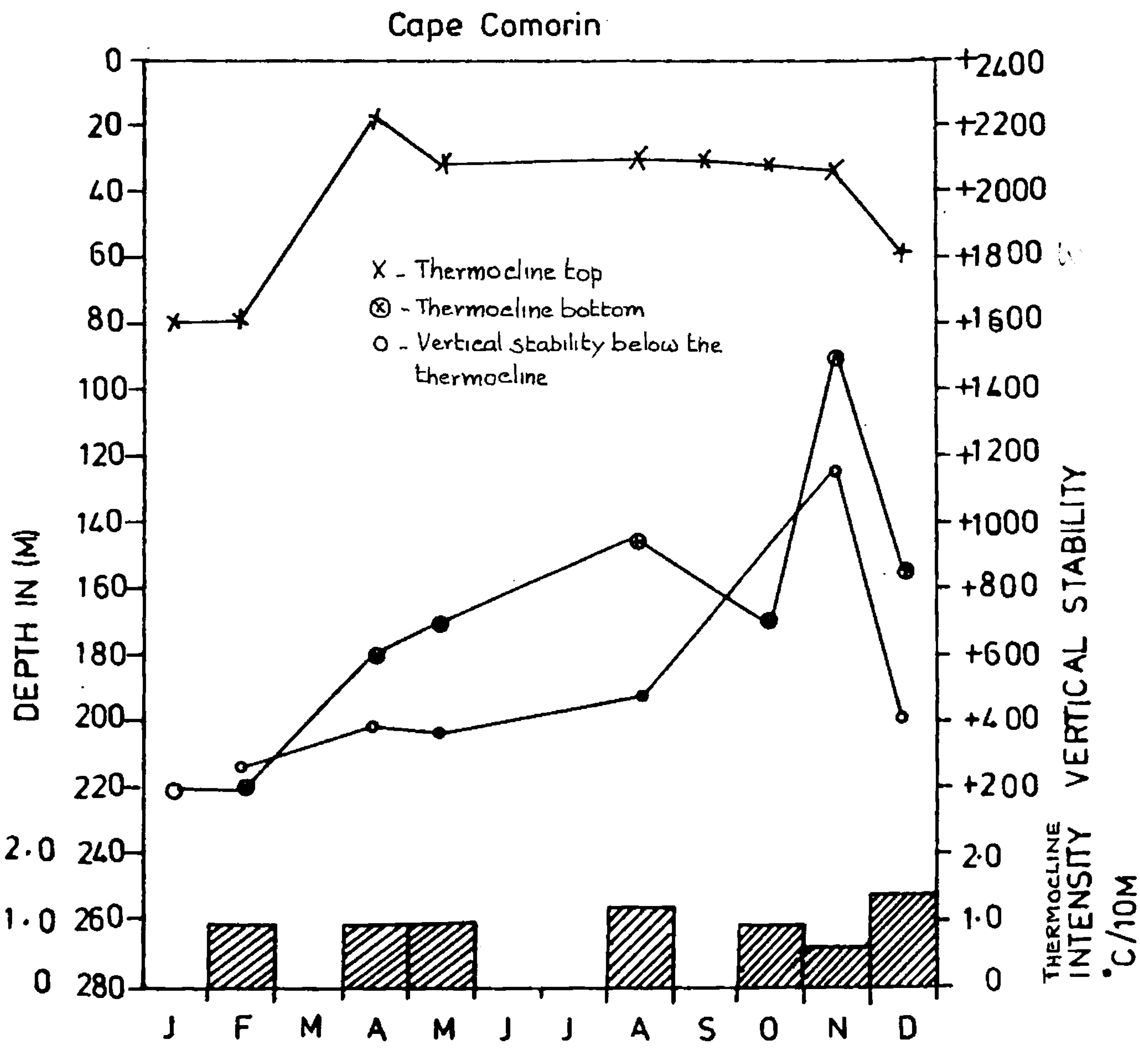
F I G. 10. B.

Vertical time section for sea water temperature off Ratnagiri (1975)


1975
J F M A M J J A S O N D J F M A M J J A S O N D
DEPTH IN METRES
0
10
20
30
50
75
100
125
150
29
28
28
27
25
23
21
19
17

F I G. 13. A

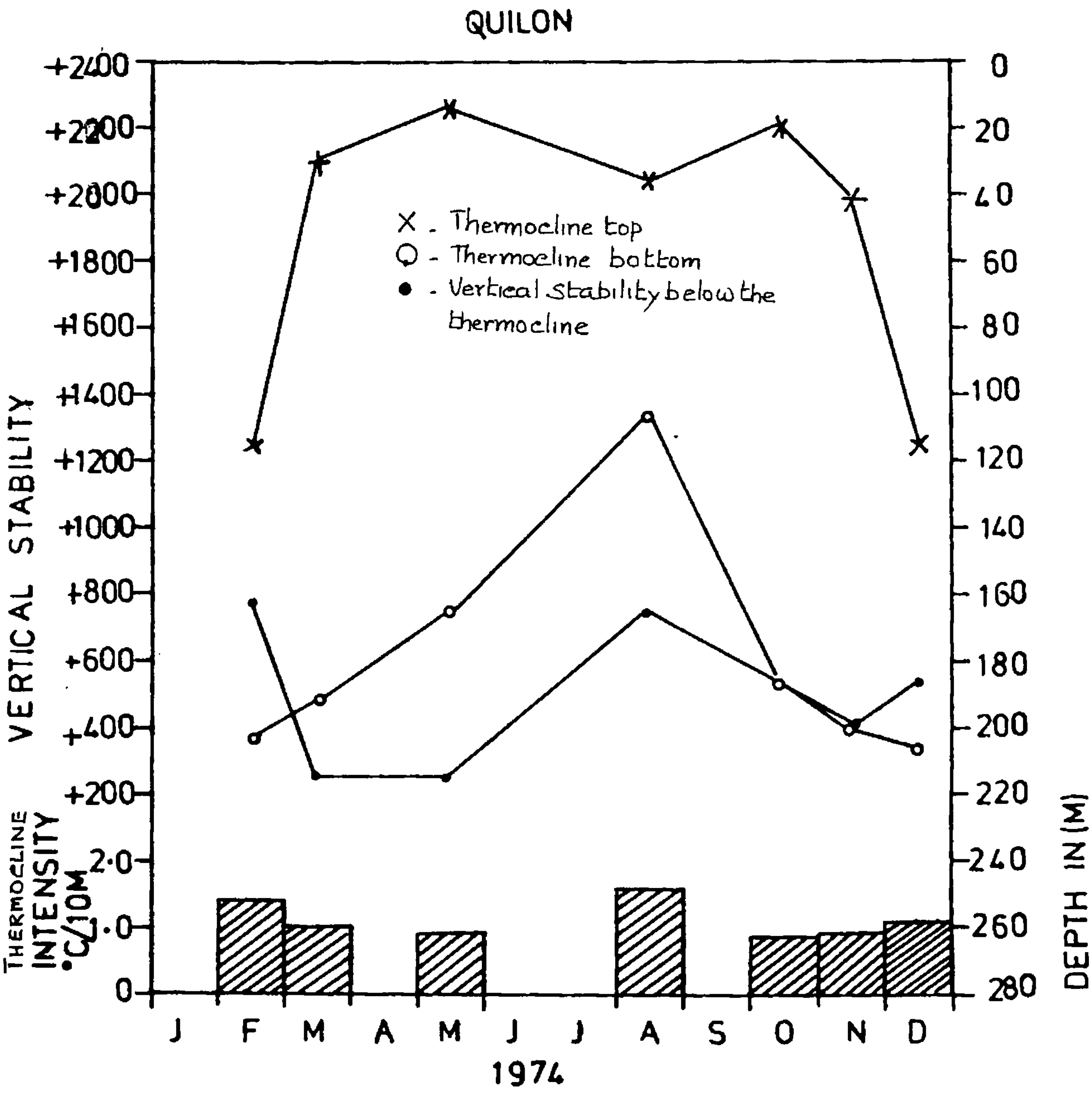
Relationship between the depth of thermocline, width of thermocline, intensity of thermocline and the vertical stability immediately below the thermocline (average upto 500 m. depth) off Cape-comorin (1974)



Cape Comorin
X - Thermocline top
⊗ - Thermocline bottom
o - Vertical stability below the thermocline
DEPTH IN (M)
VERTICAL STABILITY
THERMOCLINE INTENSITY °C/10M
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
2·0
1·0
0
+2400
+2200
+2000
+1800
+1600
+1400
+1200
+1000
+800
+600
+400
+200
2·0
1·0
0
J F M A M J J A S O N D

FIG. 13. B

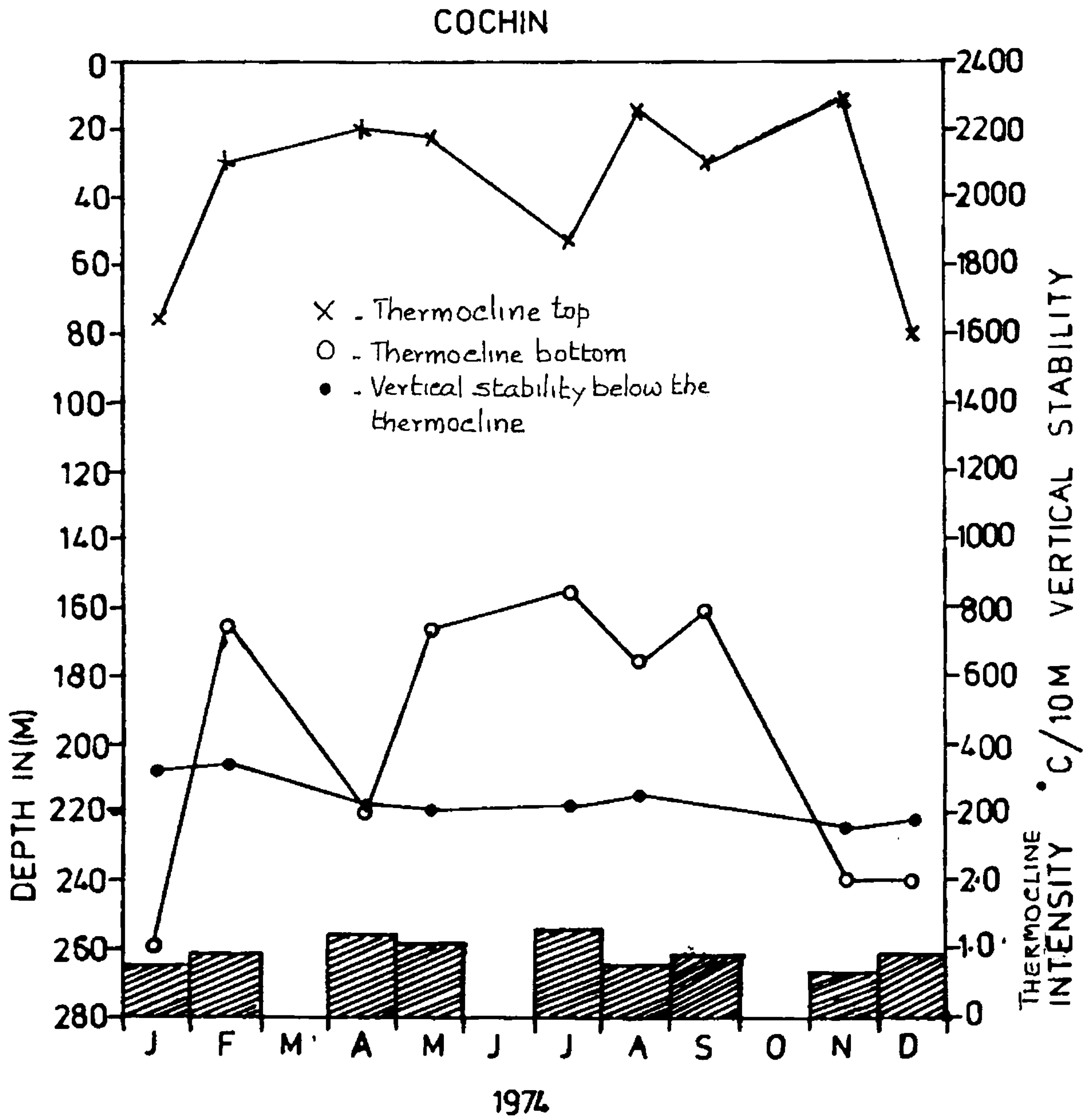
Relationship between the depth of thermocline, width of thermocline, intensity of thermocline and the vertical stability immediately below the thermocline (average upto 500 m. depth) off Quilon (1974)



QUILON
X - Thermocline top
O - Thermocline bottom
• - Vertical stability below the thermocline
VERTICAL STABILITY
+2400
+2200
+2000
+1800
+1600
+1400
+1200
+1000
+800
+600
+400
+200
THERMOCLINE INTENSITY °C/10M
2·0
1·0
0
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
DEPTH IN (M)
J F M A M J J A S O N D
1974

F I G. 13. C

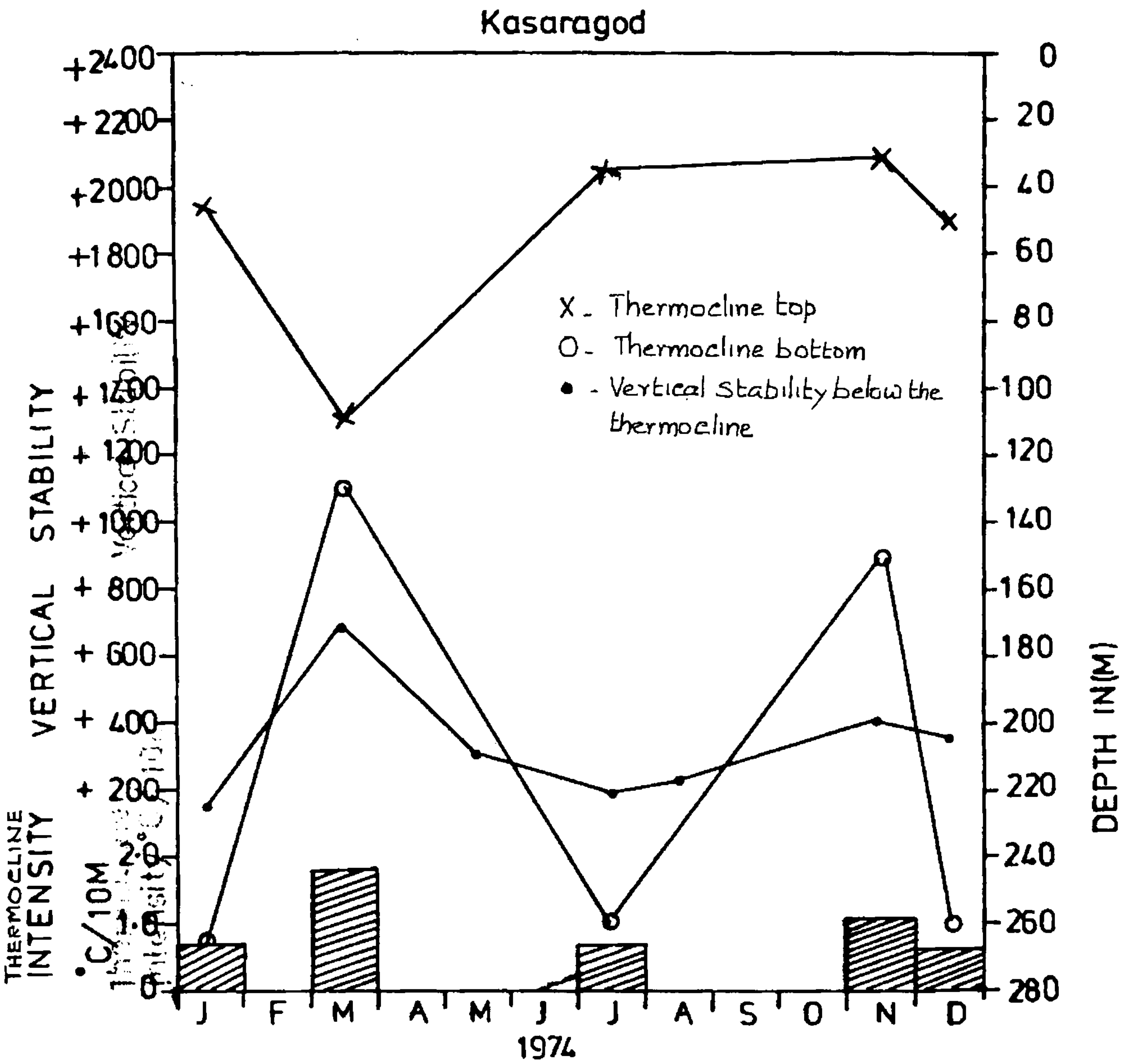
Relationship between the depth of thermocline, width of thermocline, intensity of thermocline and the vertical stability immediately below the thermocline (average upto 500 m. depth) off Cochin (1974)



COCHIN
X - Thermocline top
O - Thermocline bottom
• - Vertical stability below the thermocline
DEPTH IN (M)
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
2·0
1·0
0
VERTICAL STABILITY °C/10M
THERMOCLINE INTENSITY
J F M A M J J A S O N D
1974

FIG. 13. D

Relationship between the depth of thermocline, width of thermocline, intensity of thermocline and the vertical stability immediately below the thermocline (average upto 500 m. depth) off Kasaragod (1974)

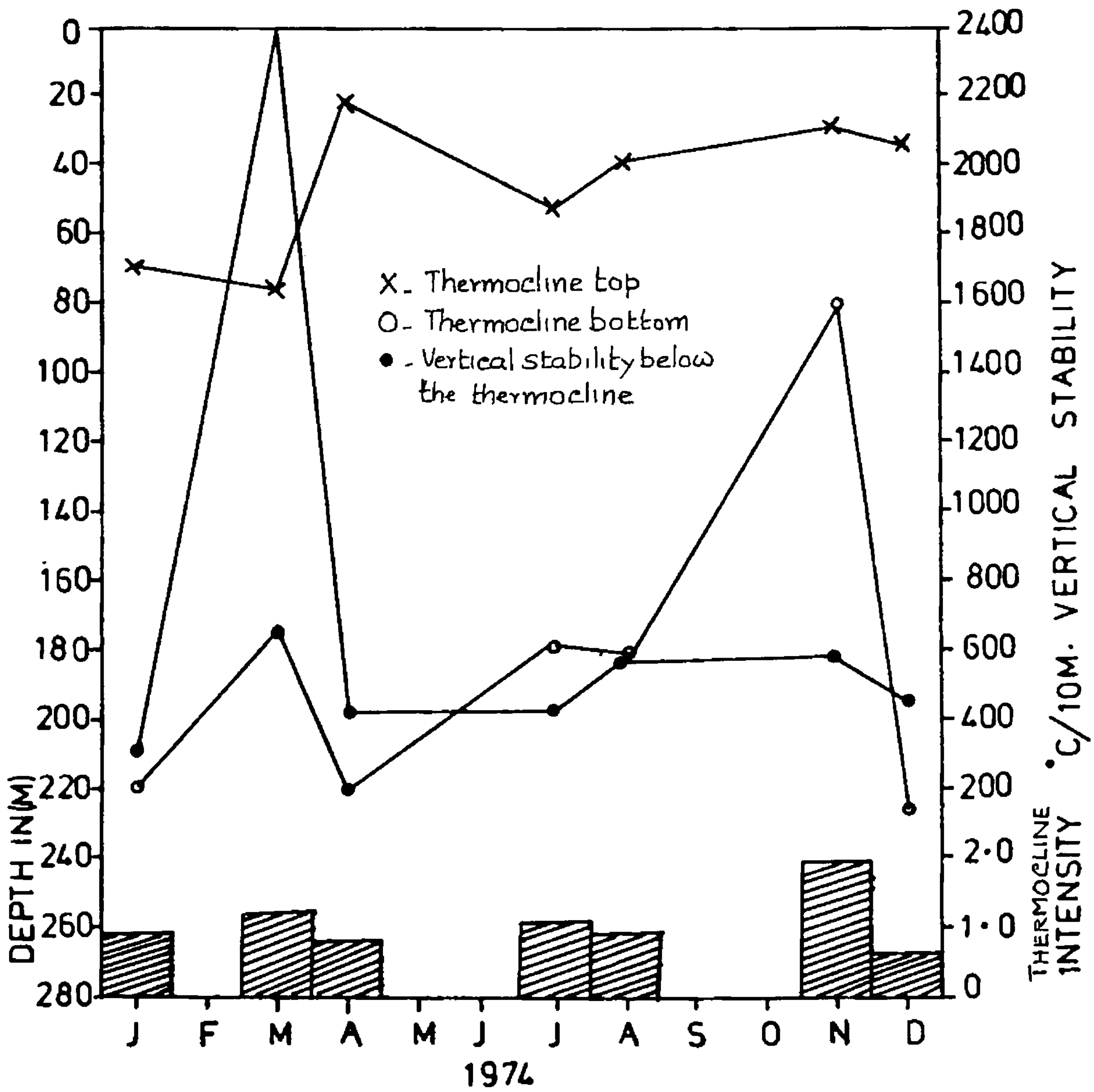


Kasaragod
X - Thermocline top
O - Thermocline bottom
• - Vertical stability below the thermocline
VERTICAL STABILITY
THERMOCLINE INTENSITY °C/10M
DEPTH IN(M)
+2400
+2200
+2000
+1800
+1600
+1400
+1200
+1000
+800
+600
+400
+200
2.0
1.0
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
J F M A M J J A S O N D
1974

F I G. 13. E

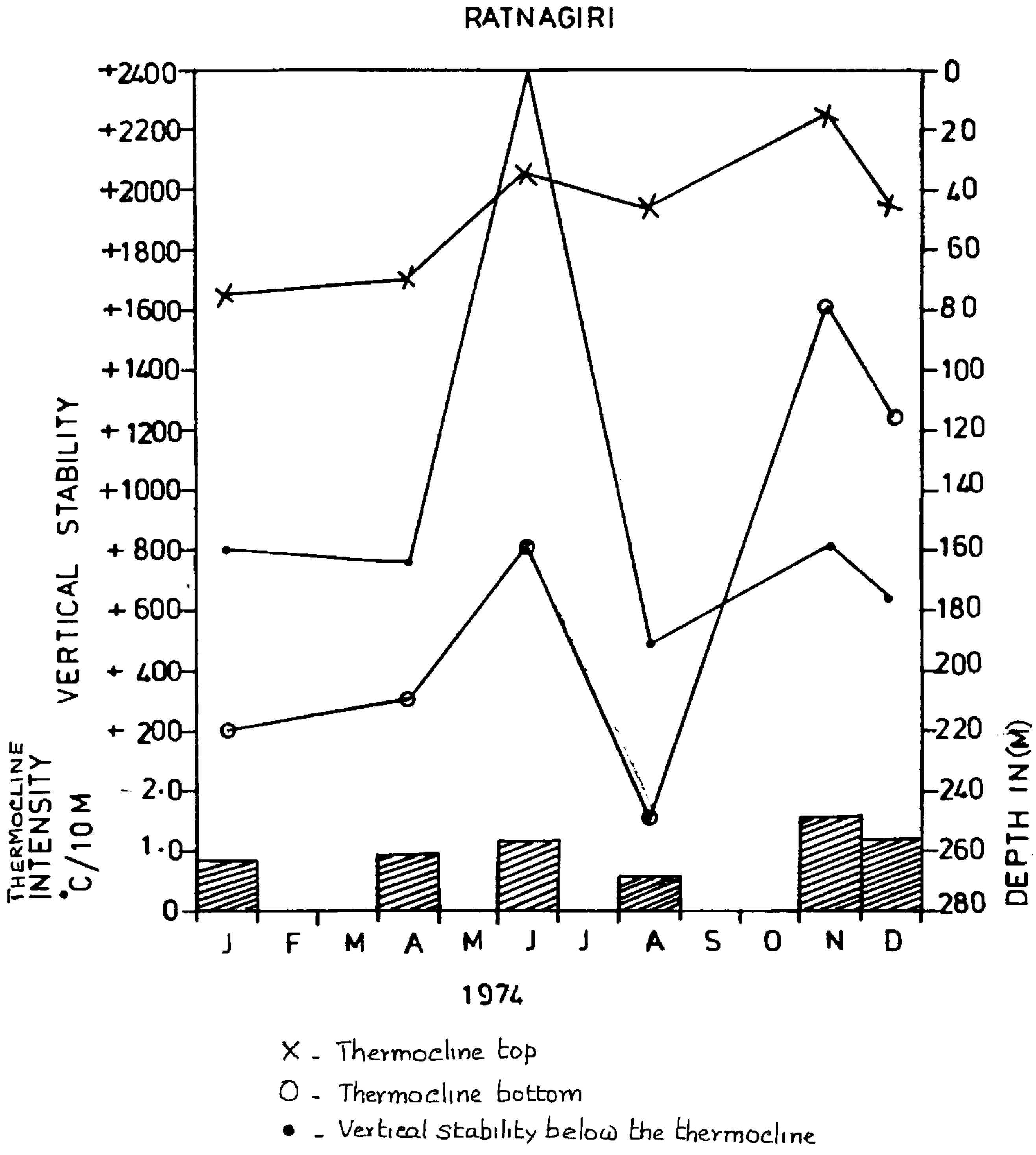
Relationship between the depth of thermocline, width of thermocline, intensity of thermocline and the vertical stability immediately below the thermocline (average upto 500 m. depth) off Karwar (1974)

KARWAR


X - Thermocline top
O - Thermocline bottom
● - Vertical stability below the thermocline
DEPTH IN (M)
°C/10M. VERTICAL STABILITY
THERMOCLINE INTENSITY
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
2·0
1·0
0
J F M A M J J A S O N D
1974

F I G. 13. F

Relationship between the depth of thermocline, width of thermocline, intensity of thermocline and the vertical stability immediately below the thermocline (average upto 500 m. depth) off Ratnagiri (1974)



RATNAGIRI
VERTICAL STABILITY
+2400
+2200
+2000
+1800
+1600
+1400
+1200
+1000
+800
+600
+400
+200
THERMOCLINE INTENSITY °C/10 M
2·0
1·0
0
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
DEPTH IN (M)
J F M A M J J A S O N D
1974
X - Thermocline top
O - Thermocline bottom
• - Vertical stability below the thermocline

Table-7

Monthly mean sea surface temperature values (°c)
at the different sections (1973-1978)

| Month | Cape | Quilon | Cochin | Kasaragod | Karwar | Ratnagiri |
|---|---|---|---|---|---|---|
| January | 27.73 | 28.26 | 28.07 | 27.56 | 27.09 | 27.04 |
| February | 26.96 | 27.88 | 28.28 | 28.02 | 27.65 | 26.50 |
| March | 28.67 | 29.12 | 29.39 | 29.21 | 28.39 | 28.77 |
| April | 28.73 | 29.82 | 30.01 | 29.70 | 29.46 | 27.83 |
| May | 27.23 | 28.24 | 29.05 | 29.46 | 30.15 | 30.03 |
| June | 26.10 | 27.42 | 27.70 | 28.28 | 28.65 | 29.55 |
| July | 24.87 | 24.96 | 25.04 | 27.09 | 26.64 | 27.84 |
| August | 21.13 | 24.58 | 24.11 | 23.17 | 24.71 | 27.99 |
| September | - | 24.26 | 23.57 | 21.78 | 25.57 | 27.56 |
| October | 25.31 | 25.98 | 27.18 | 27.01 | 23.86 | 27.78 |
| November | 27.98 | 28.20 | 28.05 | 26.68 | 27.35 | 28.26 |
| December | 27.09 | 28.47 | 28.12 | 28.56 | 27.94 | 27.05 |

the very surface both off Quilon and Cape-comorin.

Salinity:

The monthly mean sea surface salinity for the period 1973-1978 for the different sections indicated two peaks, one during May-June just before the onset of the south-west monsoon and another during September-October immediately after the south-west monsoon (Table-8). The lowest values were associated with the monsoon rain and the river runoff which showed lot of variations from one section to the other in different years. The monthly mean surface salinity varied between 32.50‰ and 36.12‰. The salinity maximum characterstic of tropical oceans was found at depths of 100 to 150 m. during the north-east monsoon and between 30 to 50 during the south-west monsoon. The variations in salinity which are mainly brought about by the rainfall, river runoff and the prevailing seasonal surface currents are characterstic of the surface layers above the salinity maximum layer. The surface salinity maximum was highest at the Karwar and Ratnagiri sections during May/June (35.6‰ to 36.12‰). Comparatively low salinity waters (33.03‰) were observed at the surface at Cape-comorin in December when the equatorial surface waters were advected northwards. Sewell (1929) attributed the lowering of salinity during December and January in the Palk Bay and Gulf of Mannar to the southerly current along the east coast. During this month the salinity values at the surface showed a steady increase from 33.03‰ off Cape-comorin to 35.08 off Karwar and Ratnagiri.

The maxima occured comparatively late in the southern sections and these were mainly associated with the advection of the high salinity Arabian Sea Water in the southerly flow and the presence of high salinity bottom water brought upward to the surface levels in areas where upwelling activity was observed. The minima were associated with the monsoon rain and the resultant river runoff and also the incursion of the low salinity equatorial surface waters in the northerly flow. The minima occured first in the southern region and progressively moved northwards following the trend in monsoon rain fall and the development of the northerly flow.

In general sections north of Kasaragod exhibited comparatively higher salinity conditions than the southern sections. At greater depths between 100 and 500m. there is a decreasing trend in salinity values north to south. In the section off Quilon and Cape-comorin this feature is observed as a salinity maximum at the depth of the thermocline. Here the northern Arabian Sea corresponds to the sub-tropical zone of high salinity. The salinity maximum at the depth of the thermocline represents an intrusion of high-saline water from the subtropical high salinity zone towards the equatorial zone below the less saline surface layer. It is quite likely that the comparatively high-saline north Arabian Sea waters are spreading southwards slowly losing their high salinity characteristics. This is in agreement with the general circulation in the upper layers in tropical and sub-tropical waters. The salinity maximum associated with the main thermocline probably represents an intrusion of high-saline waters below the

Table-8

**Monthly mean sea surface salinity values (‰) at the different sections (1973-1978)**

| Month | Cape | Quilon | Cochin | Kasaragod | Karwar | Ratnagiri |
|---|---|---|---|---|---|---|
| January | 34.51 | 34.09 | 33.70 | 32.71 | 32.90 | - |
| February | 33.91 | 33.34 | 33.66 | 34.43 | 35.62 | 35.46 |
| March | 34.21 | 34.03 | 34.33 | 34.16 | 33.84 | 34.90 |
| April | 33.79 | 34.69 | 34.31 | 34.64 | 35.13 | 35.63 |
| May | 34.95 | 34.90 | 35.11 | 35.55 | 36.12 | 36.02 |
| June | 34.71 | 35.23 | 35.21 | 34.64 | 35.60 | 35.83 |
| July | 34.93 | 34.66 | 34.63 | 35.07 | 34.41 | 35.14 |
| August | 34.99 | 34.70 | 34.43 | 34.94 | 34.89 | 34.81 |
| September | - | 34.97 | 35.22 | 35.29 | 35.32 | 35.63 |
| October | 35.26 | 35.34 | 34.77 | 34.71 | 35.26 | 34.78 |
| November | 34.35 | 34.66 | 34.67 | 34.53 | 35.45 | 35.19 |
| December | 33.03 | 33.69 | 32.50 | 34.20 | 35.08 | 35.08 |

less saline surface layers towards the equator. The monthly variations noticed in the mean sea-surface salinity values at the different sections is given in Table-8.

Dissolved Oxygen:

Dissolved oxygen content of the surface layers showed large variations in space and time. In general the shelf waters were well aerated during most of the year except during the south-west monsoon and the associated upwelling season(July-August-September). At majority of sections, a good correlation between the depth of the top of thermocline and oxycline was observed. By May, the oxygen deficient waters slowly started penetrating the shelf. The upward tilting of the isolines of oxygen and the relative position of the oxycline are indicated in the vertical time sections for the southern region (Quilon-Fig. 6) and the northern region (Karwar Fig. 9). By June-July the oxygen deficient waters penetrated below the thermocline and covered the entire bottom of the shelf. In August the oxycline became very shallow and in areas of upwelling the low oxygen intermediate water reached the very surface. The oxygen deficient water remains on the shelf until October, especially in areas where upwelling was intense. By December once again the shelf waters became well aerated. The mean monthly sea surface oxygen values for the period 1972-1978 ranged between 5.35ml $O_2$/L and 1.10 ml $O_2$/L (Table-9). Off the shelf, there is a well developed oxycline which is found approximately at the same depth as the thermocline. Below the oxycline, in general, the oxygen concentrations are higher in the southern sections when compared to the northern sections. Off Ratnagiri

Table-9

Monthly mean sea surface dissolved oxygen values (ml/L) at the different sections (1973-1978)

| Month | Cape | Quilon | Cochin | Kasaragod | Karwar | Ratnagiri |
|---|---|---|---|---|---|---|
| January | 4.61 | 4.64 | 4.91 | 4.65 | 3.00 | 4.33 |
| February | 4.91 | 4.97 | 4.82 | 4.90 | 4.89 | 4.61 |
| March | 4.54 | 4.52 | 4.64 | 4.40 | 4.61 | 4.79 |
| April | 4.67 | 4.50 | 4.58 | 4.23 | 4.63 | 4.62 |
| May | 3.91 | 4.46 | 4.71 | 4.65 | 4.69 | 4.61 |
| June | 4.26 | 4.23 | 4.22 | 4.43 | 4.44 | 5.02 |
| July | 4.03 | 3.75 | 3.71 | 3.15 | 3.73 | 4.33 |
| August | 2.30 | 3.72 | 3.83 | 2.14 | 3.32 | 4.54 |
| September | - | - | 2.46 | 1.10 | 5.35 | 4.30 |
| October | 4.20 | 4.22 | 3.34 | 4.43 | 1.39 | 4.53 |
| November | 4.55 | 5.76 | 4.60 | 3.88 | 4.00 | 4.67 |
| December | 4.64 | 4.56 | 4.62 | 4.98 | 4.97 | 5.04 |

the observed oxygen values were zero at depths below 200-400m. and it is likely that hydrogen sulphide was present at these levels.

A comparison of monthly mean dissolved oxygen values for the period 1972-1978 indicated the presence of comparatively low oxygen values during August/September at the southern sections. The low oxygen values corresponded with the period of peak upwelling in these areas when the oxygen depleted intermediate waters reached the surface levels. In general, concentration of dissolved oxygen at the surface levels during the upwelling season showed variations, the concentration showing an increase towards northern sections corresponding to the decrease in the intensity of upwelling beyond Karwar. The period, for which the oxygen deficient waters remain on the continental shelf, is longer in the northern region off Karwar than in the southern region. Off Karwar the period is nearly 6 months.when compared to nearly 2 months off Quilon.

<u>Density:</u>

The monthly mean density (at a depth of 10m at the 2nd station from the coast) for the period 1973-1978 varied between $\sigma_t$ 20.87 and 24.52 (Table-10). Comparatively high density waters were characteristic of northern sections and also those of the southern stations where the high density bottom waters reached the surface layers due to upwelling. The presence of high density waters at the surface levels near the coast, especially in the central and southern region during

Table-10

## Monthly mean sea surface density values ($\sigma_t$) at the different sections (1973-1978)

| Month | Cape | Quilon | Cochin | Kasaragod | Karwar | Ratnagiri |
|---|---|---|---|---|---|---|
| January | 22.12 | 21.64 | 21.38 | 20.87 | 21.15 | - |
| February | 21.90 | 21.16 | 21.40 | 22.69 | 23.00 | 22.09 |
| March | 21.59 | 21.31 | 21.40 | 21.37 | 21.40 | 23.24 |
| April | 21.26 | 21.58 | 21.24 | 21.58 | 22.00 | 22.95 |
| May | 22.58 | 22.26 | 22.15 | 21.96 | 22.53 | 22.50 |
| June | 22.78 | 22.74 | 22.67 | 22.23 | 22.64 | 22.51 |
| July | 23.32 | 22.92 | 23.04 | 22.75 | 23.02 | 22.57 |
| August | 24.47 | 23.25 | 22.93 | 23.84 | 23.35 | 22.27 |
| September | - | 23.50 | 24.01 | 24.52 | 23.41 | 23.04 |
| October | 22.87 | 22.95 | 22.49 | 22.57 | 23.86 | 22.31 |
| November | 21.92 | 22.49 | 22.14 | 22.44 | 22.94 | 22.47 |
| December | 21.38 | 21.27 | 22.25 | 21.73 | 22.50 | 23.05 |

the south-west monsoon season clearly indicated areas of upwelling. Under normal conditions, the density is found to be more dependent on temperature during the pre-monsoon and post-monsoon seasons whereas it is dependent on the rainfall and river runoff during the monsoon season. This is especially the case at the surface where large variations in density were noticed from one season to another.

Relationship between some of the major hydrographic parameters:

Sea water temperature and dissolved oxygen:

A good correlation between the depth of the top of thermocline and oxycline was observed at almost all the sections. In general it was found that values between 1 and 2 ml $O_2$/L were associated with temperatures between 22°c and 23°c. A comparative study of the vertical time sections for temperature and dissolved oxygen clearly indicated the above correlation especially during the south-west monsoon season when the 23°c isotherm reached the surface levels at the southern and central regions. Thus it was found that the associated isotherm could very well be used to judge average dissolved oxygen concentration at a particular depth.

Density ( $\sigma_t$) and dissolved oxygen:

During the south-west monsoon season, in areas where the upwelling activity was intense, the surface waters were characterised by comparatively low oxygen concentrations, and high density. Perhaps the

Table-11

## Mean depths of top of thermocline at the different oceanographic sections (1973-1978)

| Section | Shallowest (m) | Period | Deepest (m) | Period |
|---|---|---|---|---|
| Ratnagiri | 11 | Oct. Nov. | 39 | Dec. Jan. Feb. |
| Karwar | 10 | Oct. Nov. | 61 | Do |
| Kasaragod | 13 | Jun. Jul. Aug. Sept. | 56 | Do |
| Cochin | 10 | Jun. Jul. Aug. Sept. | 61 | Do |
| Quilon | 16 | Do | 66 | Do |
| Cape-comorin | 20 | Do | 63 | Do |
| Tuticorin | 32 | Do | 78 | Do |

Table - 12

**Position of 23°C isotherm (Sectionwise/yearwise) within the area under observation**

| Section | 1973 | | 1974 | | 1975 | | 1976 | | 1977 | | 1978 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. |
| Cape | | | | | | | | | | | | |
| Depth in | Mar. | Jul. | Feb. | Octo. | Feb. | Jul. | Feb. | Jul. | Feb. | Jul. | Feb. | Jul. |
| ms. | 110 | 57 | 140 | 43 | 120 | 45 | 115 | 42 | 115 | 0 | 115 | 53 |
| Quilon | Jan. | Jul. | Feb. | Oct. | Feb. | Sep. | Feb. | Aug. | Feb. | Jul. | Feb. | Jul. |
| Depth in ms. | 115 | 20 | 140 | 23 | 132 | 15 | 127 | 15 | 127 | 0 | 127 | 32 |
| Cochin | Jan. | Aug. | Jan. | Aug. | Feb. | Sep. | Feb. | Aug. | Mar. | Jul. | Jan. | Jul. |
| Depth in ms. | 110 | 17 | 130 | 16 | 113 | 17 | 124 | 16 | 110 | 7 | 112 | 24 |
| Kasaragod | Feb. | Aug. | Jan. | Aug. | Mar. | Aug. | Jan. | Aug. | Jan. | Jul. | Jan. | Aug. |
| Depth in ms. | 128 | 27 | 110 | 32 | 122 | 30 | 144 | 17 | 144 | 27 | 144 | 27 |
| Karwar Depth in | | | | | | | | | | | | |
| ms. | Feb. | Sep. | Jan. | Nov. | Mar. | Oct. | Jan. | Aug. | Jan. | Sep. | Jan. | Oct. |
| | 128 | 16 | 120 | 34 | 138 | 35 | 134 | 48 | 134 | 22 | 134 | 15 |
| Ratnagiri | | | | | | | | | | | | |
| Depth in | Feb. | Nov. | Jan. | Nov. | Feb. | Oct. | | | Feb. | Sep. | Feb. | Oct. |
| ms. | 125 | 50 | 122 | 56 | 170 | 45 | - | - | 170 | 70 | 170 | 70 |

correlation may exist only for a short duration as the addition of fresh Water from rain and river runoff at the surface levels increase the stability of the water column, thereby resisting any vertical mixing. When the upwelled water remains at the surface, it gets aerated by direct contact with the atmosphere.

Density ( $\sigma_t$ ) and sea water temperature.

Under normal conditions, in the tropical oceans, with increasing depth, the temperature decreases and density increases showing an inverse relationship between density and temperature.

During the monsoon period, at the surface level, the density is dependent on temperature and salinity. Once the process of upwelling sets in, high salinity bottom waters of comparatively low temperature are brought up towards the surface levels. The characteristics of this water mass will change within a short time when more of fresh water is added to the system, thereby effecting a fall in density and an increase in temperature brought about by solar radiation, thus once again stabilising the water column.

Vertical stability characteristics of the surface layers:

The various mixing processes within a water body are, to a great extent, controlled by the vertical stability conditions which in turn makes a particular region of the sea fertile or barren. As pointed out earlier by cooper (1960), the replenishment of the surface waters of the oceans by nutrients from below is dependent on the vertical stability of the water column and hence the proper assessment of the parameter will help us to find out probable areas of upwelling and sinking.

Vertical stability parameter in the sea is denoted by the expression "E" = $10^{-3} \frac{d\sigma_t}{dz}$ (Hesselberg, 1918) where $\frac{d\sigma_t}{dz}$ is the individual change in density with depth. When "E" is positive, the stratification along the vertical plane is stable and when it is negative, the stratification becomes unstable. Between positive and negative stability)layers there is always a surface where "E" = 0 (neutral stability). The order of magnitude of the different terms in the equation has been computed by Hesselberg and Sverdrup (1914-1915) and it was shown that $\frac{d\sigma_t}{dz}$ is an accurate expression of the stability up to a depth of 100m.

In order to obtain a general picture of stability conditions prevailing within the continental shelf area necessary computations were made for 31 stations (first one representing the coastal conditions, second one the mid-shelf conditions and the third one the conditions at the edge of the continental shelf) along the sections located off Cape-comorin, Quilon, Cochin, Kasaragod, Karwar and Ratnagiri upto a depth of 100m.

In general, in the absence of large scale vertical mixing caused by upwelling and sinking, the vertical stability increased at the top of the thermocline probably due to the effect of sudden lowering of temperature with depth. In order to have a general comparison, the stability values pertaining to the year 1974, for the different months/

sections are presented in Table 13 A to F. Some work along these lines has been attempted by Sastry (1957) and Ramamirtham and Nair (1964) at selected areas in the Bay of Bengal and Arabian sea. Sundararamam et al (1963) observed that the instability noticed in the upper layers in the northern and central Arabian sea during the post-monsoon season is the consequence of the transition between the south-west monsoon and the north-east monsoon.

According to Sastry (1957), when conditions are not stationary and in the presence of intense mixing, as he observed at two neighbouring stations located off Visakhapatnam, the stability criterion gives divergent results. He has also concluded that off Visakhapatnam over the continental shelf the changes in the vertical stability with depth are due to mixing in the offshore drift produced by upwelling. More or less similar divergent results have been obtained for the shelf stations occupied during the south-west monsoon period when the offshore drift gets established in areas where upwelling becomes intense. The vertical stability conditions off Cape-comorin (May-August), Quilon (July-August), Cochin (July-August) and Kasaragod (July-August) clearly indicate the effect of the offshore drift during the south-west monsoon period. Comparatively low values of stability/ instability were observed at 11 stations during the period of survey viz. December-February (Cape-comorin), December (Quilon), November-January (Cochin) November (Kasaragod), December-February (Karwar) and January-April (Ratnagiri). The negative values of stability observed at the surface levels during the months April-May-June-July off Karwar and Ratnagiri

Table-13A

Vertical stability characteristics of the shelf waters (0-500m. depth)

along the South West coast of India (1974-values) (expressed as $10^{8}E$)

1. Coastal station 2. Mid-shelf station 3. Outershelf station

- Nagative stability
+ Positive stability
0 Neutral stability

CAPE-COMORIN

| Depth Inter-val(m) | FEBRUARY | | | APRIL | | | MAY | | | AUGUST | | | NOVEMBER | | | DECEMBER | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| 0-10 | +200 | -300 | -300 | +500 | +600 | +1800 | +1900 | +900 | -300 | +400 | +800 | +1100 | +1500 | +1000 | +400 | -0 | -0- | 2000 |
| 10-20 | | -0- | -0- | | +2700 | +2100 | | +800 | +400 | +4600 | +1700 | +2200 | -1100 | +2200 | +600 | | | -0- |
| 20-30 | | -0- | -0- | | +1700 | +1000 | | +2200 | -0- | | +7300 | +4500 | | +1600 | +1600 | | | +4000 |
| 30-50 | | -0- | -0- | | +4900 | +1800 | | +4900 | +4600 | | +3700 | +4000 | | | +900 | | | +6000 |
| 50-75 | | | +80 | | | +3300 | | | +3000 | | | +2000 | | | +1300 | | | +3000 |
| 75-100 | | | +2500 | | | +4000 | | | +4200 | | | | | | +2000 | | | +3500 |
| 100-125 | | | +4000 | | | +4100 | | | +1500 | | | +1700 | | | +3000 | | | +3200 |
| 125-150 | | | +1500 | | | +2000 | | | +1000 | | | +1000 | | | +2500 | | | +1000 |
| 150-200 | | | +1800 | | | +1200 | | | +1000 | | | | | | +1500 | | | |
| 200-250 | | | | | | | | | | | | +300 | | | +900 | | | |
| 250-300 | | | | | | | | | | | | +300 | | | | | | |
| 300-400 | | | | | | | | | | | | +100 | | | | | | |
| 400-500 | | | | | | | | | | | | | | | | | | |

**Table - 13 B.**

**Vertical stability characteristics of the shelf waters (0-500m. depth) along the South West coast of India (1974-values)(expressed as $10^{8}$ E)**

1. Coastal station 2. Mid-shelf station 3. Outershelf station

\- Negative stability
\+ Positive stability
O Neutral stability

QUILON

| Depth Interval(m) | FEBRUARY 1 | 2 | 3 | MARCH 1 | 2 | 3 | MAY 1 | 2 | 3 | AUGUST 1 | 2 | 3 | NOVEMBER 1 | 2 | 3 | DECEMBER 1 | 2 | 3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | +1000 | -0- | +500 | +4600 | -0- | +1400 | +8900 | +1100 | +1300 | +7400 | +700 | +2300 | +5000 | +7300 | +400 | -300 | +200 | +300 |
| 10-20 | | +4900 | | | +1400 | | | +2700 | +10200 | | +5500 | +9300 | | +2400 | +500 | | +1200 | |
| 20-30 | | +950 | +2800 | | +800 | +4250 | | +7300 | +2100 | | +4600 | +2000 | | +1100 | +2100 | | +7600 | -0- |
| 30-50 | | +2800 | +1550 | | +1000 | +4000 | | +3800 | +2200 | | +1650 | +6500 | | +1050 | +2200 | | +1450 | +4500 |
| 50-75 | | +1300 | +3000 | | +240 | +3300 | | +1100 | +2600 | | +1000 | +3900 | | +1080 | +2800 | | +400 | +1800 |
| 75-100 | | | +600 | | +8100 | +4700 | | +410 | +2800 | | | +2600 | | +1400 | +2600 | | | +1600 |
| 100-125 | | | +1300 | | | +3040 | | | +430 | | | +1080 | | | | | | +400 |
| 125-150 | | | +2700 | | | +1440 | | | +2700 | | | +808 | | | +800 | | | +800 |
| 150-200 | | | +5000 | | | +880 | | | +1200 | | | +880 | | | +1540 | | | +3180 |
| 200-250 | | | +1960 | | | +340 | | | | | | | | | | | | +1550 |
| 250-300 | | | +820 | | | +840 | | | +470 | | | +270 | | | +760 | | | +1060 |
| 300-400 | | | +240 | | | + 200 | | | +180 | | | +160 | | | +270 | | | +270 |
| 400-500 | | | +130 | | | +120 | | | +120 | | | +120 | | | +170 | | | +160 |

Table-13C.

Vertical stability characteristics of the shelf waters (0-500m. depth) along the South West coast of India (1974-values) (expressed as $10^8E$)

1. Coastal station  2. Mid-shelf station  3. Outershelf station

- Negative stability
+ Positive stability
0 Neutral stability

COCHIN

| Depth interval (m) | JANUARY 1 | JANUARY 2 | JANUARY 3 | FEBRUARY 1 | FEBRUARY 2 | FEBRUARY 3 | APRIL 1 | APRIL 2 | APRIL 3 | MAY 1 | MAY 2 | MAY 3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | | +600 | -100 | +5300 | +700 | +300 | +2200 | +2700 | | +2500 | +200 | -0- |
| 10-20 | | +500 | | | +1800 | | | +3000 | +2770 | | +400 | +400 |
| 20-30 | | +1900 | +1700 | | +1600 | +2150 | | +7500 | +500 | | +6900 | [illegible] |
| 30-50 | | +4450 | +200 | | +700 | +5350 | | +2550 | +7700 | | +1650 | +5450 |
| 50-75 | | | +2100 | | | +2800 | | | +3800 | | | +2500 |
| 75-100 | | | +3040 | | | +1400 | | | +1800 | | | +2200 |
| 100-125 | | | +1200 | | | +2800 | | | +3600 | | | +1700 |
| 125-150 | | | +1300 | | | +3600 | | | +2000 | | | +2300 |
| 150-200 | | | +4200 | | | +1340 | | | +980 | | | +1320 |
| 200-250 | | | +740 | | | +1040 | | | +550 | | | |
| 250-300 | | | +380 | | | +380 | | | | | | +560 |
| 300-400 | | | +200 | | | +160 | | | +240 | | | +290 |
| 400-500 | | | +60 | | | +140 | | | +100 | | | +170 |

(Contd. next page).

Table 13 C. (Contd.)

Vertical stability characteristics of the shelf waters (0-500m.depth)

along the South West coast of India (1974- values) (expressed as $10^{8}E$)

1. Coastal station 2. Mid-shelf station 3. Outershelf station

COCHIN

- Negative stability
+ Positive stability
o Neutral stability

| Depth Inter-val(m) | JULY | | | AUGUST | | | NOVEMBER | | | DECEMBER | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| 0-10 | | +9800 | +4400 | | | +20500 | +17900 | +800 | -100 | | | +600 |
| 10-20 | | +6200 | +6700 | +6200 | +7200 | +3400 | | +4000 | +3200 | | | |
| 20-30 | | +4300 | +3800 | | +10100 | +2400 | | +3700 | +1300 | | +11800 | +3250 |
| 30-50 | | +900 | +3000 | | +2300 | +1450 | | +700 | +4000 | | +7200 | +1350 |
| 50-75 | | | +1100 | | | +810 | | | +1600 | | | +2000 |
| 75-100 | | | +1600 | | | +1320 | | | +1700 | | | +800 |
| 100-125 | | | +1700 | | | +1100 | | | +1200 | | | +800 |
| 125-150 | | | +1300 | | | +1200 | | | +1700 | | | +1000 |
| 150-200 | | | +800 | | | +1040 | | | +840 | | | +4180 |
| 200-250 | | | | | | | | | | | | +1240 |
| 250-300 | | | | | | + 310 | | | +640 | | | +640 |
| 300-400 | | | +380 | | | +160 | | | +220 | | | +100 |
| 400-500 | | | +220 | | | + 130 | | | +140 | | | |

**Vertical stability characteristics of the shelf waters (0-500m. depth)**

**along the South-West coast of India (1974-values) (expressed as $10^8 E$)**

1. Coastal Station  2. Mid-shelf station  3. Outershelf station

\- Negative stability
\+ Positive stability
O Neutral stability.

KASARAGOD

| Depth inter-val(m) | January | | | March | | | MAY | | | July | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| 0.10 | +800 | + 400 | +1600 | +3000 | +2100 | +2300 | +11300 | +800 | +3300 | - | -500 | +800 |
| 10.20 | | +100 | +2300 | | +300 | | | +100 | +3500 | | +5500 | -0- |
| 20.30 | | -0- | + 7500 | | +5800 | +5800 | | +3900 | +6200 | | +11600 | -0- |
| 30.50 | | +13800 | +4400 | | +4450 | +200 | | +8700 | +2800 | | +1600 | +5700 |
| 50.75 | | | +2000 | | | +3700 | | +600 | +5400 | | | +2700 |
| 75.100 | | | +4000 | | | +2000 | | | +2600 | | | +2700 |
| 100.125 | | | +3000 | | | +4000 | | | +1000 | | | +1000 |
| 125.150 | | | + 2600 | | | +2500 | | | +300 | | | +1200 |
| 150.200 | | | +1700 | | | +1800 | | | +1200 | | | +8800 |
| 200.250 | | | | | | +800 | | | | | | |
| 250.300 | | | +690 | | | +400 | | | +470 | | | +390 |
| 300.400 | | | +240 | | | +240 | | | +330 | | | +220 |
| 400.500 | | | +100 | | | +150 | | | +150 | | | +160 |

**Table 13 D** - Contd.

**Vertical stability characteristics of the shelf waters (0-500m. depth) along the South-West coast of India (1974-values) (expressed as $10^8 E$)**

1. Coastal Station 2. Mid-shelf station 3. Outershelf station

\- Negative stability
\+ Positive stability
O Neutral stability.

KASARAGOD

| Depth interval (m) | August 1 | August 2 | August 3 | November 1 | November 2 | November 3 | December 1 | December 2 | December 3 |
|---|---|---|---|---|---|---|---|---|---|
| 0-10 | | + 30,100 | +500 | +10900 | +8600 | -100 | -0- | +300 | +200 |
| 10-20 | | +3000 | -0- | | + 13000 | +1900 | | +400 | +4900 |
| 20-30 | | +300 | +2400 | | +3300 | +900 | | +700 | +2400 |
| 30-50 | | +1300 | +3800 | | +400 | +6900 | | +100 | +600 |
| 50-75 | | +700 | +1700 | | -0- | +3000 | | | +400 |
| 75-100 | | | +1700 | | | +700 | | | |
| 100-125 | | | +1600 | | | +1200 | | | +1400 |
| 125-150 | | | +1700 | | | +1200 | | | + 240 |
| 150-200 | | | +600 | | | + 700 | | | +800 |
| 200-250 | | | +360 | | | +500 | | | +970 |
| 300-400 | | | +170 | | | +200 | | | +540 |
| 400-500 | | | +130 | | | +150 | | | +180 |

## Vertical stability characteristics of the shelf waters (0-500m. depth) along the South-West coast of India (1974-values) (expressed as $10^8 E$)

1. Coastal station  2. Mid-shelf station  3. Outershelf station

- Negative stability
+ Positive stability
O Neutral stability

KARWAR

| Depth Interval (m) | JANUARY 1 | JANUARY 2 | JANUARY 3 | MARCH 1 | MARCH 2 | MARCH 3 | APRIL 1 | APRIL 2 | APRIL 3 | JULY 1 | JULY 2 | JULY 3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | -0- | +400 | +200 | +1100 | +3400 | -200 | +700 | +1900 | +200 | - | -900 | -0- |
| 10-20 | | +600 | +4300 | | +2300 | +1400 | | +900 | | | +4100 | |
| 20-30 | | +5100 | +7200 | | +4100 | +1700 | | +7000 | +2950 | | +18500 | +100 |
| 30-50 | | +4030 | +3900 | | +4850 | +4800 | | + 5450 | +5600 | | +2200 | -0- |
| 50-75 | | | +1000 | | | +3600 | | | +2500 | | | +5700 |
| 75-100 | | | +2400 | | | +1300 | | | +3600 | | | +2900 |
| 100-125 | | | +3400 | | | +3300 | | | +2900 | | | +1200 |
| 125-150 | | | +3000 | | | +2400 | | | +2350 | | | +1100 |
| 150-200 | | | + 1340 | | | +3300 | | | +1800 | | | +920 |
| 200-250 | | | | | | | | | +840 | | | +500 |
| 250-300 | | | +670 | | | | | | +400 | | | +360 |
| 300-400 | | | +190 | | | | | | +230 | | | +190 |
| 400-500 | | | +100 | | | | | | +200 | | | +100 |

Table-13(E) Contd.

**Vertical stability characteristics of the shelf waters(0.500m. depth) along the South-West coast of India (1974-values) (expressed as $10^8 E$)**

1. Coastal station 2. Mid-shelf station 3. Outershelf station

\- Negative stability
\+ Positive stability
0 Neutral stability

KARWAR

| Depth interval(m) | AUGUST 1 | AUGUST 2 | AUGUST 3 | NOVEMBER 1 | NOVEMBER 2 | NOVEMBER 3 | DECEMBER 1 | DECEMBER 2 | DECEMBER 3 |
|---|---|---|---|---|---|---|---|---|---|
| 0-10 | | +400 | +400 | +17700 | +20000 | + 300. | -200 | -400 | +100 |
| 10-20 | | +8200 | -0- | | +10100 | +1600 | | +300 | -0- |
| 20-30 | | +20000 | + 100 | | +3800 | +2700 | | +300 | +100 |
| 30-50 | | +2500 | +4700 | | +600 | +5600 | | +2800 | +2650 |
| 50-75 | | | +1500 | | | +2100 | | | +810 |
| 75-100 | | | +2040 | | | +1000 | | | +700 |
| 100-125 | | | +1300 | | | +810 | | | +1500 |
| 125-150 | | | +1600 | | | +100 | | | +2300 |
| 150-200 | | | +860 | | | +1140 | | | +1680 |
| 200-250 | | | | | | | | | |
| 250-300 | | | +690 | | | +500 | | | +930 |
| 300-400 | | | + 160 | | | +220 | | | +250 |
| 400-500 | | | | | | +160 | | | +170 |

**Table 13 F**

**Vertical stability characteristics of the shelf waters(0-500m.depth) along the South-West coast of India (1974-values) (expressed as $10^8 E$)**

1. Coastal Station  2. Mid-shelf station  3. Outershelf station

- Negative stability
+ Positive stability
0 Neutral stability

RATNAGIRI

| Depth Interval(m) | JANUARY 1 | JANUARY 2 | JANUARY 3 | MARCH 1 | MARCH 2 | MARCH 3 | APRIL 1 | APRIL 2 | APRIL 3 | JUNE 1 | JUNE 2 | JUNE 3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | + 200 | +800 | -300 | -100 | -100 | +1900 | -200 | -100 | +200 | +2200 | +1000 | -300 |
| 10-20 | | +200 | +2200 | | +3000 | +2700 | +700 | -100 | | | +300 | -0- |
| 20-30 | | +2300 | | | +4200 | -600 | | +5200 | +4400 | | +900 | +100 |
| 30-50 | | +500 | +1200 | | +1400 | +2950 | | +3900 | +2600 | | +6800 | +7500 |
| 50-75 | | | +2600 | | | +1100 | | | +2400 | | | +1700 |
| 75-100 | | | +1200 | | | +2040 | | | +5700 | | | +2500 |
| 100-125 | | | +2600 | | | +720 | | | +1700 | | | +2700 |
| 125-150 | | | +2800 | | | +1640 | | | +1100 | | | +2800 |
| 150-200 | | | +800 | | | +2360 | | | | | | |
| 200-250 | | | | | | +1040 | | | +2160 | | | |
| 250-300 | | | | | | +480 | | | +440 | | | |
| 300-400 | | | | | | | | | +200 | | | |
| 400-500 | | | | | | | | | +160 | | | |

(Contd. . .next page).

**Vertical stability characteristics of the shelf waters(0-500m. depth) along the south-West coast of India (1974-values) (expresed as $10^{8}E$)**

1. Coastal Station 2. Mid-shelf station 3. Outershelf Station

\- Negative stability
\+ Positive stability
O Neutral stability

RATNAGIRI

| Depth Interval(m) | AUGUST 1 | AUGUST 2 | AUGUST 3 | NOVEMBER 1 | NOVEMBER 2 | NOVEMBER 3 | DECEMBER 1 | DECEMBER 2 | DECEMBER 3 |
|---|---|---|---|---|---|---|---|---|---|
| 0-10 | | +300 | +400 | +4800 | +600 | +400 | +3300 | +200 | +200 |
| 10-20 | | -0- | -100 | | +19100 | +1400 | | | -0- |
| 20-30 | | +13800 | -0- | | +3300 | +7400 | | +2000 | -0- |
| 30-50 | | +4300 | + 350 | | +150 | +4300 | | +4200 | -0- |
| 50-75 | | | +760 | | | +360 | | +120 | +4500 |
| 75-100 | | | +1200 | | | +2600 | | | +2100 |
| 100-125 | | | +1500 | | | +1040 | | | +1100 |
| 125-150 | | | +1200 | | | | | | +400 |
| 150-200 | | | +5400 | | | +1040 | | | +1180 |
| 200-250 | | | | | | | | | |
| 250-300 | | | +1220 | | | +470 | | | +710 |
| 300-400 | | | +170 | | | +230 | | | +370 |
| 400-500 | | | +60 | | | +130 | | | +130 |

might possibly be associated with the effectiveness of evaporation in these latitudes. The resultant increase in salinity and decrease in temperature (evaporation causes cooling) leads to an increase in density and to a reduction in stability. Ramamirtham and Nair (1964) while studying the stability characterstics of the surface waters off Cochin during the different seasons observed vertical turbulance near the bottom during the monsoon and early post-monsoon seasons. Existence of comparatively less stable conditions at the bottom levels during the south-west monsoon period, resulting out of the upwelling process, is evident from a uniform decrease in the stability conditions below a depth of 50m.

The author feels that the unstable conditions resulting out of the sinking process during the winter season (November-February) results in comparatively low values of stability/instability conditions at the surface levels. In fact the reduction in stability at the surface levels could very well be indicative of the existence, duration and intensity of the process of sinking. In the case of the upwelling process, the unstable conditions are more revealed at the bottom levels with uniform decrease in the vertical stability values below a depth of 50m. The effect of the offshore drift resulting out of the process of upwelling give rise to divergent stability values at the neighbouring stations both on the vertical and horizontal plane.

Fig. 13 gives the variation of vertical stability below the thermocline (s), thermocline intensity in terms of $0^{\circ}c/10$ m (I), vertical spread (width) of the thermocline (T) and top depth of the thermocline (D),. From the general trend of the figures, the following conclusions may be drawn.

When the water column below the thermocline exhibits comparatively low values of stability, the top depth of thermocline is shallow and at the same time the vertical spread of thermocline is large. When the intensity of thermocline is high, its vertical spread is minimum.

Below the thermocline, the vertical stability is comparatively low during the south-west monsoon period all along the coast. However, the strength of thermocline does not vary uniformly along the coast. It's strength is more during the south-west monsoon period in the waters south of Kasaragod and during post-monsoon in the waters north of Kasaragod. With regard to the intensity of thermocline, Kasaragod demarcates the border line. During the south-west monsoon the stability below the thermocline is the least and correspondingly the top depth of thermocline also occurs at comparatively shallower waters. But the vertical spreading of the thermocline during this season is large.

During the south-west monsoon, the waters south of Kasaragod indicate least stability below the thermocline. The effect of low stability brings the top depth of thermocline closer to the sea surface with a large vertical spread of thermocline. During the same season the effect of increased intensity of thermocline tends to push the thermocline to the deeper depth with the lowest vertical spread. The extent of vertical spread of thermocline could be taken as an index of upwelling. Therefore, upwelling during this season, in these waters, is mainly effected by comparatively weak stabilities below the thermocline. Since the top depth of the thermocline is shallowest during this season, it may be said that the effect of intencified thermocline is negligible when compared to that of low stability below the thermocline.

In spite of the high intensity of the thermocline in these waters during this season, because of the strong effect of the low stability occuring below the thermocline, the waters are upwelled.

North of Kasaragod the stability below the thermocline is high and the intensity of thermocline relatively low during the south-west monsoon period. Thus the conditions of stability are not favourable for promoting upwelling in the waters north of Kasaragod during the south-west monsoon season.

Thermal Inversions:

A thermal inversion can result in the presence of a surface current where some of the water in the thermocline may also move in the direction of flow overriding the deepwater. Similar inversions are roughly ' S ' shaped (Lafond,1954 ). The auther observed thermal inversions in the northern Arabian sea during the months March -April and their absence in May is attributed to the comparatively weak circulation system prevailing in this region during the transition period between the northerly and southerly currents.

A careful examination of the bathythermograms pertaining to the different stations/sections for the period 1971-1978 indicated that thermal inversions, generally associated with the bottom of the thermocline, were characteristic of all the stations except during the months August -September (Tuticorin ), May-June and September ( Cape-comorin), April and September (Quilon) August and September (Cochin), May, June and July (Kasaragod) and June, July and September (Ratnagiri). The thermal inversions were mostly found at the surface levels during the south-west monsoon/upwelling season and their depth of occurrence was maximum during the winter season. Their absence was noticed during the transition period between the northerly and southerly currents.

Vertical mixing processes:

Upwelling:

Upwelling is the process in the sea whereby the sub-surface waters move up towards the surface layers. This phenomenon is of great significance in the biological productivity of the sea. The reason for higher production in upwelling areas is due to the high fertility effected by the basic nutrient salts ( nitrates, silicates,phosphates etc.) brought up to the well lighted upper layers of the seas. Here the resident population of lower plants (phytoplankton) synthesize organic plant matter (primary production) from the inorganic substances with the help of sunlight (photosynthesis) and multiply. A chain action is followed by secondry production of animal plankton (zooplankton) and finally plankton feeding fishes and their predators congregate in such productive areas for feeding. The phenomenon of upwelling was explained qualitatively by Thorade (1909) and subsequently developed by McEwen

(1934). Sverdrup (1930,1938) Sverdrup and Fleming (1941), Hidaka (1954,1955) Gunther (1936) etc., have added to our knowledge of the phenomenon.

Coastal upwelling areas of the world lie mostly along the western coasts of the continents. Coasts of Peru, California, north-west and south-west Africa, west coast of India etc., are good examples of such areas. Exceptions to this pattern are found along the north-eastern African coast, Somali coast and east coast of Arabia, east coast of India etc. Localised upwelling is found around areas of divergences. Whereever upwelling is influenced by monsoon wind system and accompanying currents, the phenomenon is more seasonal. In coastal upwelling areas sediments rich in organic matter are found. Attempts have also been made to chart upwelling areas by mapping phosphatic deposits (Dragesund 1970).

The economic benefit of upwelling is mainly due to the large concentrations of commercially important fishes in these areas. Most of these resources consist of clupeoid fishes with short food chains (feeding on lower plants and animal-plankton) and their predators like tunas.

The best example of a highly productive upwelling area is the coast of Peru with its tremendous catches of anchoveta. Other important productive upwelling areas are the south-west African coast with it's rich fisheries for pilchard and the California coast with the sardines. It is well known that major pelagic fishery resources of India like oil sardine and mackerel lie along the south west coast, where regular seasonal upwelling is prevalent. It is estimated that the upwelling areas of the world, a little over 0.1% of the ocean surface, produce about half the world's fish supply.

<u>Mechanism of upwelling:</u>

In principle the process of upwelling can take effect from one or a combination of the following situations:

Favourable offshore wind component and the resultant offshore surface drift.

Favourable nearshore current

Favourable diverging current systems

Upwelling due to a favourable offshore wind is effective along the west coasts of continents where the prevailing winds are either northerly or north-easterly during a particular season. The resulting surface drift would be deflected towards the right of the wind in the northern hemisphere by a certain angle depending upon the distance from the equator and in most cases would lead to the development of a comparatively strong offshore drift at the surface level. The offshore surface drift pushes away the surface water which is replaced by the bottom water creeping upwards (Laevastu and Hela, 1970).

In the second situation i.e a favourable nearshore current, the slow upward movement of bottom waters is caused by the effect of a nearshore current. In order to satisfy the horizontal density gradients, high density bottom waters are slowly inducted on the left side of a southerly current flowing along the west coast of a continent (Varadachari, 1961; Sharma, 1967). Along the east coast of continents, the current should have a northerly flow to satisfy the above said horizontal density gradients. As regards the actual mechanism, there is still controversy as to whether the current is instrumental for the development of the process or whether the induction of high density bottom waters is instrumental for maintaining the intensity of the flow.

Thirdly, diverging currents, especially those occurring around oceanic islands, lead to a shift of the upper water masses, at the point where the divergence takes place, which are replaced by sub-surface waters moving upwards (Pillai & Perumal 1975).

Upwelling around the Indian sub-continent

Upwelling in varying intensities has been observed along the west and east coast of India. The occurrence of the phenomenon corresponds to the onset of the south-west monsoon (summer monsoon) and the effect of the monsoon wind system and the resulting current system on the shelf waters.

Along the west coast, upwelling sets earlier in the south and progressively shifts to the north. The process commences earlier in deeper water as early as February and the effect reaches the coastal areas at the surface levels by July and continues through August to early September in the south and October in the north. The strong southerly flow with the coast on the left side induces upward motion of sub-surface water near the coast. The winds blow with the northerly component parallel to the coast till April which helps the process to intensify. The temperature discontinuity layer (thermocline) climbs up during the upwelling season and reaches the surface sometime in June/July.

Along the east coast, prior to the commencement of the south-west monsoon (April) the southerly winds are in general found to blow parallel to the coast. The coastal currents are northerly throughout the coast which is found to be favourable for the development of upwelling along the coast. As has been already indicated, in the northern hemisphere, a wind blowing parallel to the sea coast with the coastline to its left, or an offshore wind, will favour the process of upwelling.

Probable causes of upwelling along the south-west coast

The basic mechanism of upwelling along the south-west coast of India was studied in the past by several workers. According to Banse, (1968) the prevailing current system and not the wind is to be regarded as the main cause generating and maintaining the upwelling. Even if a uniform current velocity is considered all along the coast, the rise of denser, deep water will be stronger in the north farther away from the equator. He is of the opinion that off the south-west coast of India upwelling starts with the onset of the south-west monsoon and reaches the maximum intensity during July-August. Darbyshire (1967) concluded that there is no system of wind generated upwelling during the south-west monsoon period along the west coast of India and indicated that along the west coast of India the dense bottom waters approach the surface because of the immediate interplay of the current with the tilting of the sea surface and thermocline. Rao and Jayaraman (1966) and also Pillai and Perumal (1975) reported upwelling around Lakshadweep island during November/December and attributed the same to the divergence of current systems in the viscinity of the Islands. Ramamirtham and Jayaraman (1960) have stated that off Cochin upwelling starts by mid August, establishes by late September and ends by mid October. According to Sharma (1968) upwelling along the west coast of India starts earlier in the south and slowly extends towards north. He is of the opinion that the process commences at deeper depths earlier in the month of February and reaches the surface by May. The process comes to an end by July-August when the top of thermocline in the area reaches the surface layers. The influence of the river runoff and rain stratify the surface layers from July onwards thereby opposing the process.

The data under study revealed that any one of the above mentioned theories, is not directly applicable to the south-west coast of India as a whole. The causative factors which bring up the sub-surface waters to surface levels vary in space and time. The process of upwelling starts as early as February at the bottom levels. It starts at the various sections at different times each year. The commencement of the process in February was possibly initiated by the northerly winds which would transport the surface water away from the coast thereby initiating the vertical ascending motion from below. Perhaps the depth at which the motion gets started, would to a great extent, depends upon the velocity, direction and duration of the prevailing wind system in a specific area, the bottom topography, the prevailing current system at the surface levels and also on the vertical stability of the water column. The speed of the ascending motion also would depend on the continuance of the above mentioned favourable factors with more or less the same intensity. The onset of the south-west monsoon generates the Somali current (Lighthill, 1969) resulting in a general clockwise circulation in the Arabian sea which in turn develops into a relatively strong southerly current at the surface levels along the west coast of India. The comparatively cold, low-oxygenated and denser water from sub-surface levels would be slowly brought upwards along the continental shelf, very near the coast. Depending upon the intensity of the various factors which promote upwelling, sub-surface waters from comparatively greater depths reach surface levels, thereby contributing to the productivity of the surface waters in a specific area. A closer examination of the prevailing wind system during the south-west monsoon season revealed the presence of favourable northerly and north-westerly components in certain localities where the upwelling intensity also showed correspoindingly higher values. Perhaps it would be reasonable to presume that the process of upwelling along the south-west coast of India is brought about by either one or a combination of the factors mentioned above. Hence the commencement, intensity and duration of the phenomenon varies in space and time.

Effect of upwelling on hydrographic conditions:

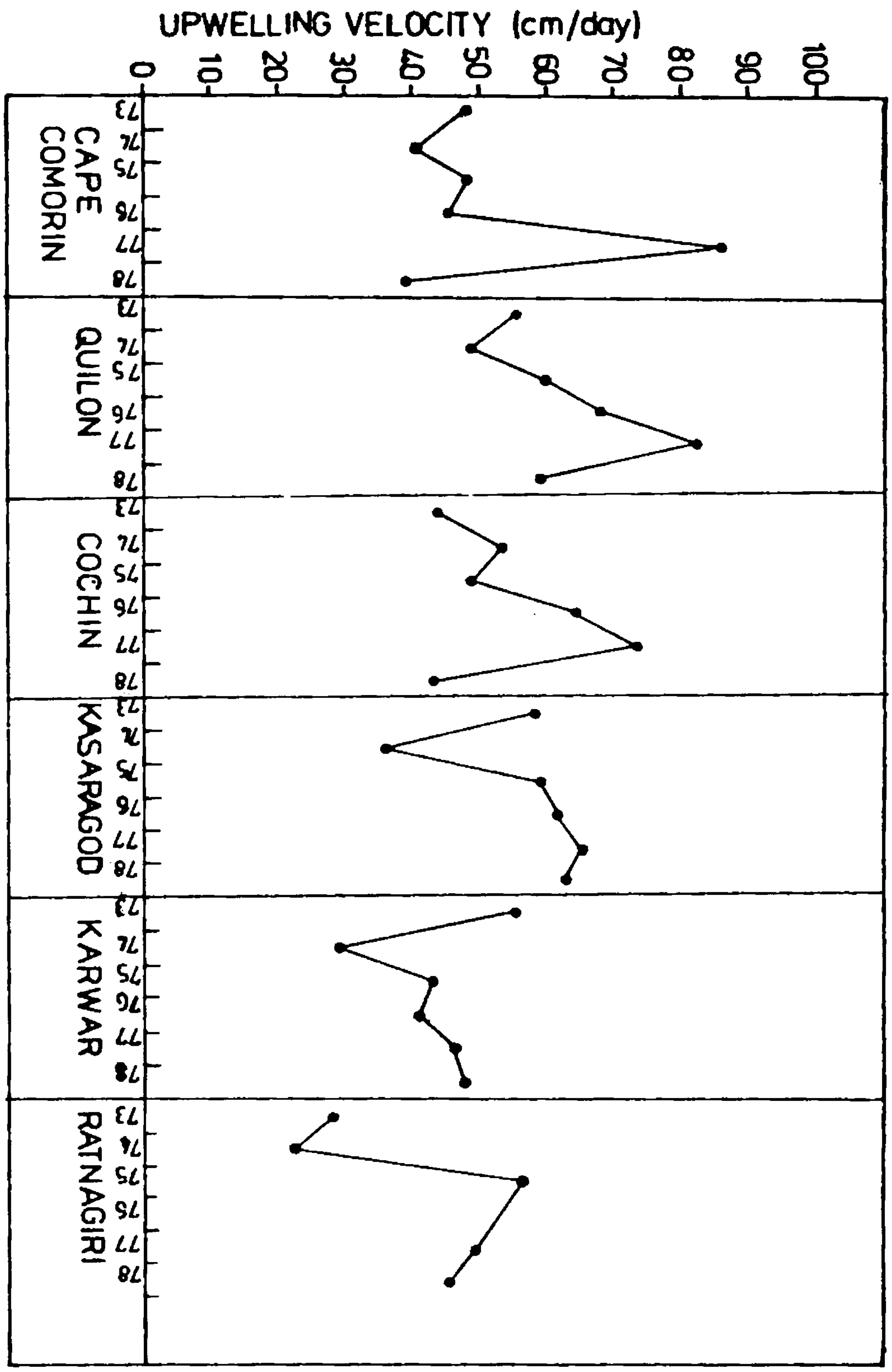
Through the process of upwelling, waters from comparatively deeper areas of the shelf are slowly brought towards surface layers along the sea bottom near the coast. These bottom waters in general are cool, dense and rich in plant nutrients and above all poor in dissolved oxygen concentration. Thus, once the phenomenon takes effect, the coastal waters exhibit a fall in temperature, dissolved oxygen content and an increase in density and nutrient contents. The present study indicated evidence of strong upwelling in areas off and south of Calicut during July, 1977. Towards north upwelling has been progressively weak. Relatively very low values of surface temperature (21.13$^{\circ}$c) and dissolved oxygen ( 1ml $O_2$/L) indicationg the presence of upwelled cool and badly aerated waters were seen at the inshore stations off Calicut and southwards. A comparison of temperature values at surface and sub-surface levels for the July-August period on the continental shelf during the period 1974-1977 showed unusually low temperature values at stations located south of Kasaragod during July, 1977 which indicated comparatively stronger upwelling during the year. Hydrographic observations carried out during the south-west monsoon season of the year 1976 revealed that the process of upwelling was pronounced south of Cochin. A survey conducted in June, 1978 revealed the presence of upwelling off Quilon. The water column got stabilised during July-August. Comparatively low temperature (23.95$^{\circ}$c), low oxygen concentration (1.46ml/L) and high density ($\sigma_t$ 23.16) were observed at the surface levels near the coast. A comparison of sea surface temperature during July-August for the period 1973-1978 indicated low values off Cape-comorin, Quilon, Calicut and Kasaragod. At most of the coastal stations the oxygen concentrations were very low with comparatively denser waters at the surface levels. It may be pointed out that one characteristic feature of upwelled water in the Arabian sea is the low oxygen content. The top of thermocline was found very near the surface at most of the coastal stations. Strong upwelling resulting in the bottom waters reaching the surface levels was observed off Kasaragod. This could be inferred from the decrease in the dissolved oxygen content at the surface levels. During October, very low surface temperature (21.7°c) was observed off Mangalore near the coast. Observations carried out off Karwar and Batnagiri confirmed that the process of upwelling extended only up to Karwar during 1978.

The upward tilting exhibited by some of the selected isolines (23°c isotherm and 1 ml $O_2$/L) in the vertical time sections prepared for the Cape-comorin, Quilon, Cochin, Kasaragod, Karwar and Ratnagiri sections clearly indicated the occurrence and intensity of the upwelling phenomenon in the area under study. Vertical velocity of upwelling at the different sections was approximately estimated after taking into consideration the net upward movement of the isotherm which exhibited maximum oscillations on the vertical plane and also the time taken to complete the said motion. It is evident from the time sections that the process of upwelling commenced earlier (January-February) in deeper (170m) waters at different sections.The intensity of upwelling was comparatively higher towards south, especially in the area south of Karwar. Vertical time sections of both temperature and oxygen were used as indicators of the upwelling process, since both these parameters influence fish distribution. The Kasaragod, Cochin and Quilon sections exhibited the lowest oxygen concentrations on the shelf. The intensity of upwelling was comparatively less off Karwar and Ratnagiri, than at the southern sections. Fig. 12 gives a diagramatic representation of the rate of the upward movement in cm per day of 23°c isotherm sectionwise/yearwise (1973-1978). The rate of ascent of the isotherm has been calculated from the vertical distance travelled and the number of days taken to cover the distance (Table 14). A comparison of the velocity at the different sections in different years indicated large variations from year to year and section to section showing the variations in the onset, intensity and duration of upwelling in different years and different sections. According to Banse (1968), upwelling which begins with the south-west monsoon causes an uplift of the 20°c isotherm by 90-100m and regular upwelling to the surface is unknown north of 15°N Latitude.

The estimates indicated that upwelling was strongest during 1977 with vertical velocities ranging from 65.4 cm/day to 86.5 cm/day in the area between Kasaragod and Cape comorin. North of Kasaragod, both off Karwar and Ratnagiri, the intensity was comparatively less throughout the period, the highest being 55.7 cm/day and 56.3 cm/day during 1973 and 1975 respectively. The least depth of occurrence of 23°c isotherm was the minimum associated with the highest velocity showing an inverse relationship between the two parameters. Off Cochin, Quilon and Cape-comorin the isotherm reached depths of 7m, 0m. and 0m. corresponding to the highest velocities of 73.6 cm, 83.0 cm and 86.5 cm/day respectively. According to McEwen (1934) the rate of upwelling in the region off San Diego computed from serial

**F I G. 12**

Diagramatic representation of the upwelling velocity (cm/day) off Cape-comorin, Quilon, Cochin, Kasaragod, Karwar and Ratnagiri during the period 1973-1978 .



UPWELLING VELOCITY (cm/day)
0
10
20
30
40
50
60
70
80
90
100
CAPE COMORIN
QUILON
COCHIN
KASARAGOD
KARWAR
RATNAGIRI
73
74
75
76
77
78

Table-14

Upwelling Intensity (sectionwise/yearwise) based on the vertical movement of 23°c Isotherm (1973-1978)

| Setion | Year | Duration (days) | Upward movement (m) | Speed Cm/ ? | Least depth (m) for 23°c Isotherm. |
|---|---|---|---|---|---|
| Cape-comorin | 1973 | 109 | 53 | 48.6 | 57 |
| | 1974 | 239 | 97 | 40.6 | 43 |
| | 1975 | 155 | 75 | 48.4 | 45 |
| | 1976 | 159 | 73 | 45.9 | 42 |
| | 1977 | 133 | 115 | 86.5 | 0 |
| | 1978 | 157 | 62 | 39.5 | 53 |
| Quilon | 1973 | 170 | 95 | 55.9 | 20 |
| | 1974 | 238 | 117 | 49.2 | 23 |
| | 1975 | 194 | 117 | 60.3 | 23 |
| | 1976 | 164 | 112 | 68.3 | 15 |
| | 1977 | 153 | 127 | 83.0 | 0 |
| | 1978 | 160 | 95 | 59.4 | 32 |
| Cochin | 1973 | 211 | 93 | 44.1 | 17 |
| | 1974 | 212 | 114 | 53.8 | 16 |
| | 1975 | 195 | 96 | 49.2 | 17 |
| | 1976 | 167 | 108 | 64.7 | 16 |
| | 1977 | 140 | 103 | 73.6 | 7 |
| | 1978 | 201 | 88 | 43.8 | 24 |
| Kasaragod | 1973 | 173 | 101 | 58.4 | 27 |
| | 1974 | 217 | 78 | 35.9 | 32 |
| | 1975 | 155 | 92 | 59.4 | 30 |
| | 1976 | 205 | 127 | 62.0 | 17 |
| | 1977 | 179 | 117 | 65.4 | 27 |
| | 1978 | 186 | 117 | 62.9 | 27 |
| Karwar | 1973 | 201 | 112 | 55.7 | 16 |
| | 1974 | 290 | 86 | 29.7 | 34 |
| | 1975 | 239 | 103 | 43.1 | 35 |
| | 1976 | 209 | 86 | 41.1 | 48 |
| | 1977 | 240 | 112 | 46.7 | 22 |
| | 1978 | 249 | 119 | 47.8 | 15 |
| Ratnagiri | 1973 | 262 | 75 | 28.6 | 50 |
| | 1974 | 290 | 66 | 22.8 | 50 |
| | 1975 | 240 | 125 | 56.3 | 45 |
| | 1976 | .. | .. | .. | .. |
| | 1977 | 202 | 100 | 49.5 | 70 |
| | 1978 | 220 | 100 | 45.5 | 70 |

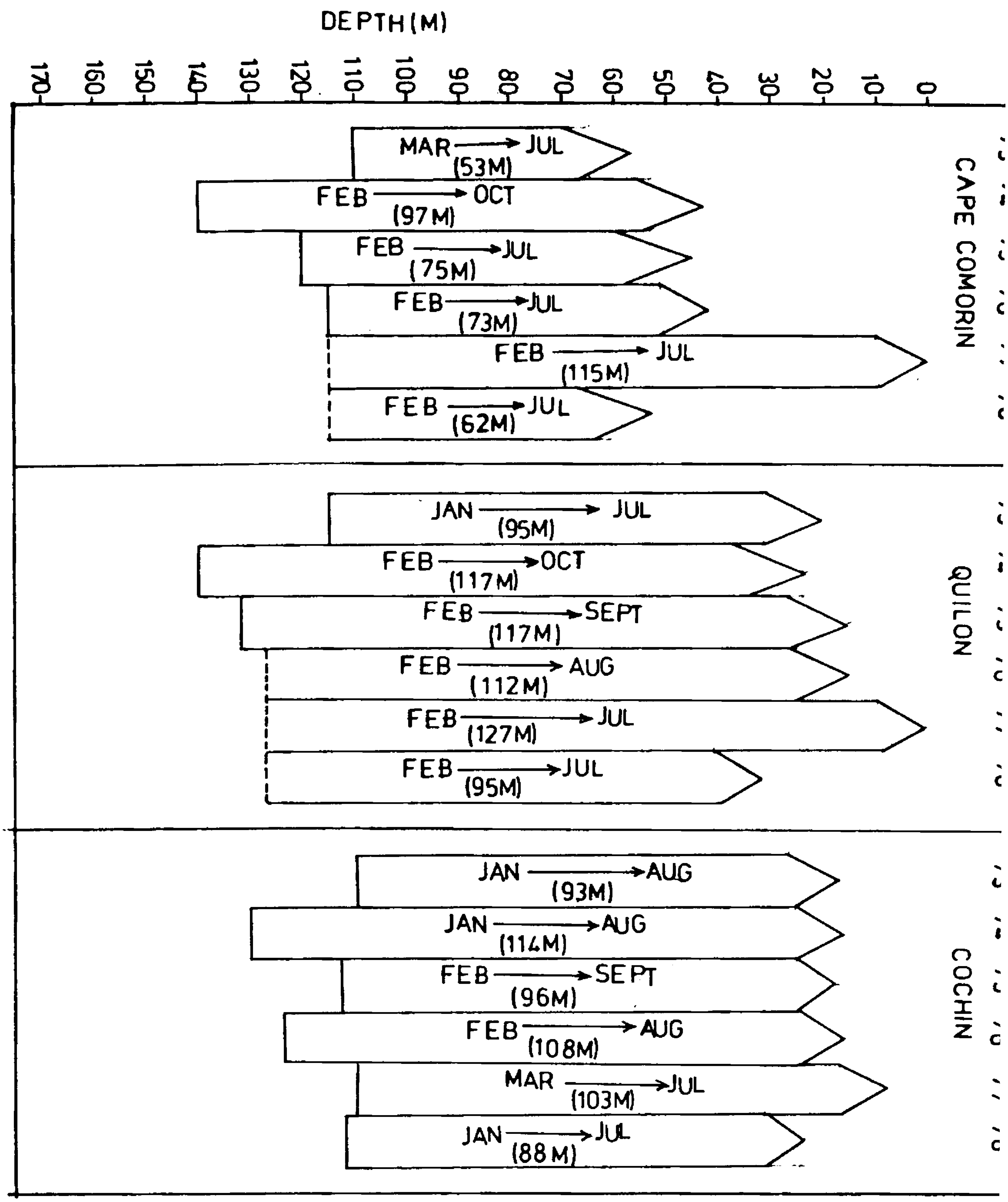
temperatures was about 66 cm/day. Figures 11A and 11B throw light on the depth at which this isotherm started tilting towards the surface each year at the different sections, the approximate duration and also the shallowest depth where the isotherm reached at the cessation of the upwelling process. The figures also indicate the net upward motion at the different sections in different years.

Yoshida and Mao (1957) found that a measure of the increase in the density of sea water at a depth of 150m. is proportional to the intensity of upwelling along the California coast. A similar correlation was attempted for the area under study. But the results did not indicate a definite correlation.

The author is of the opinion that, of the two major factors which are indicative of the process of upwelling viz. temperature and dissolved oxygen content, the former is a better indicator of the intensity of the phenomenon, since the dissolved oxygen content of the upwelled water is subject to the influence of various factors such as production and consumption of oxygen in unit time at different depths, dissolution of atmosphere oxygen and the resultant transmission due to advective process etc. Hence it is advisable to select the particular isotherm which exhibits the maximum vertical movement and watch its upward tilting as an indicator of upwelling. The dissolved oxygen values will help in confirming the presence of sub-surface waters at the surface levels and also the approximate time of the arrival of the upwelled water at the surface.

F I G. 11. A.

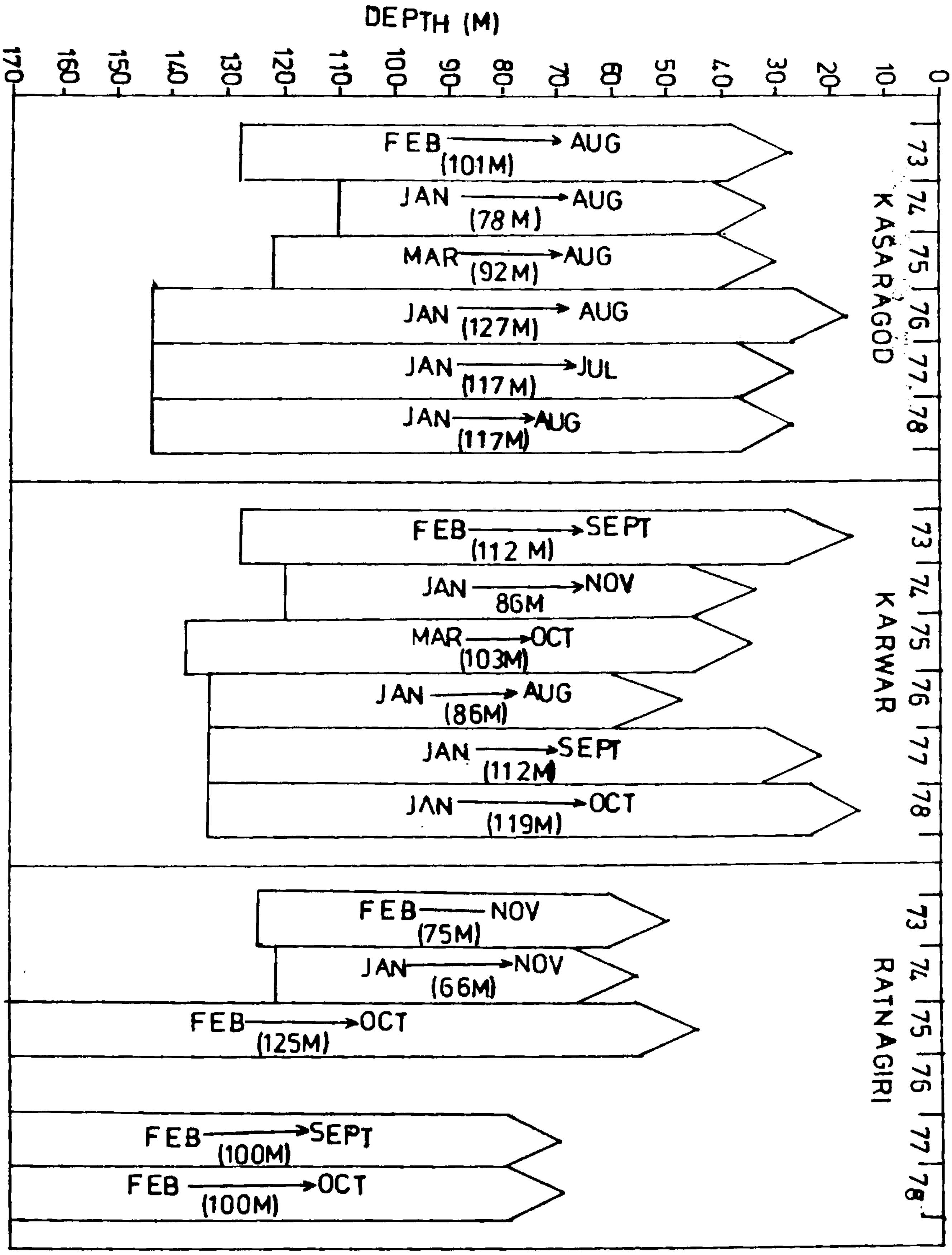
Diagramatic representation of the extent and duration of vertical tilting of the 23°C isotherm section-wise/yearwise (Cape-comorin, Quilon, and Cochin- (1973–1978)



DEPTH (M)
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170
CAPE COMORIN
MAR → JUL (53M)
FEB → OCT (97M)
FEB → JUL (75M)
FEB → JUL (73M)
FEB → JUL (115M)
FEB → JUL (62M)
QUILON
JAN → JUL (95M)
FEB → OCT (117M)
FEB → SEPT (117M)
FEB → AUG (112M)
FEB → JUL (127M)
FEB → JUL (95M)
COCHIN
JAN → AUG (93M)
JAN → AUG (114M)
FEB → SEPT (96M)
FEB → AUG (108M)
MAR → JUL (103M)
JAN → JUL (88M)

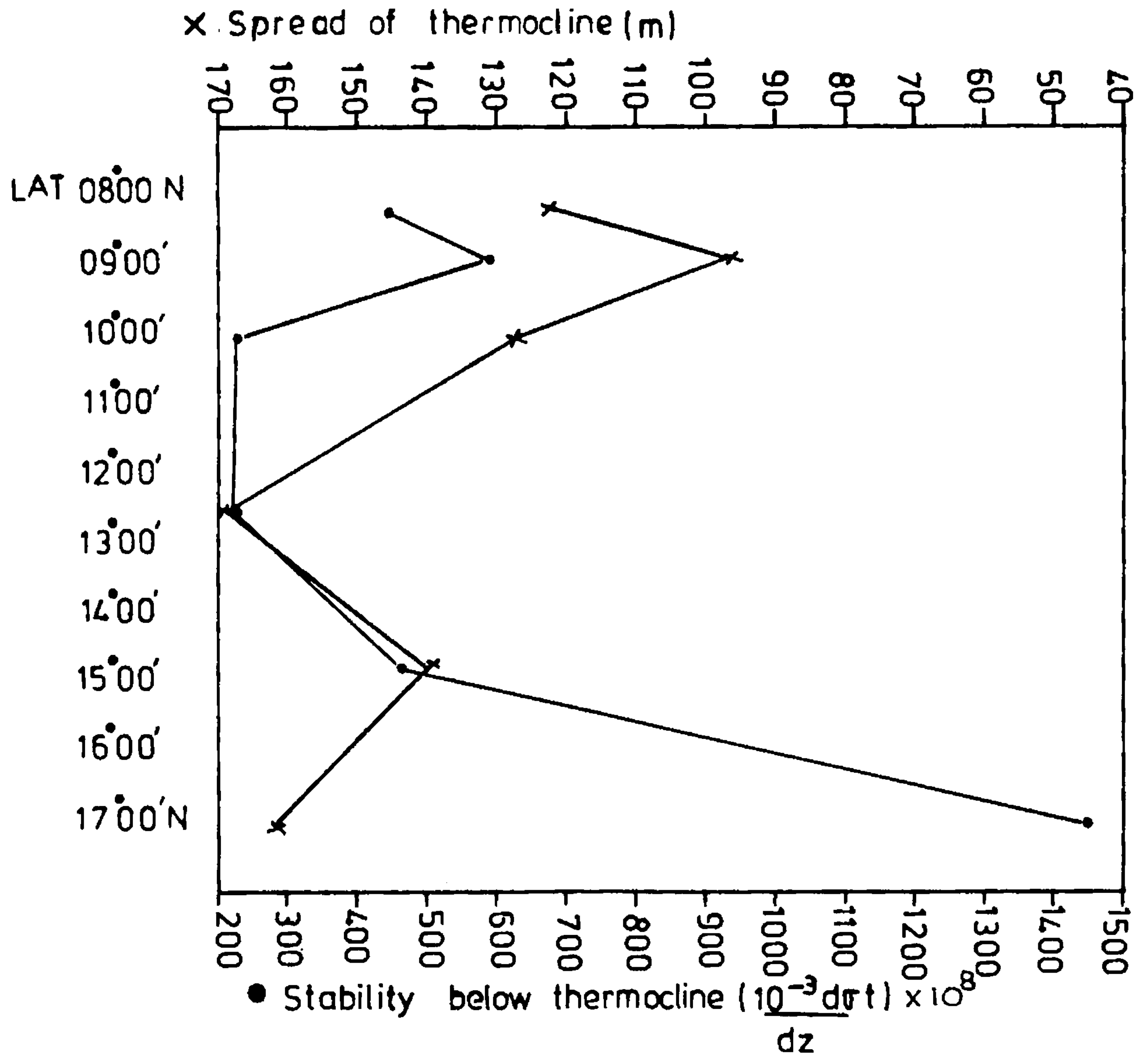
**F I G. 11. B.**

**Diagramatic** representation of the extent and duration of vertical tilting of the $23^{\circ}C$ isotherm section-wise/yearwise (Kasaragod, Karwar and Ratnagiri (1973 – 1978)


DEPTH (M)
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170
KASARAGOD
73 74 75 76 77 78
FEB → AUG (101M)
JAN → AUG (78 M)
MAR → AUG (92 M)
JAN → AUG (127M)
JAN → JUL (117 M)
JAN → AUG (117M)
KARWAR
73 74 75 76 77 78
FEB → SEPT (112 M)
JAN → NOV 86M
MAR → OCT (103M)
JAN → AUG (86M)
JAN → SEPT (112M)
JAN → OCT (119M)
RATNAGIRI
73 74 75 76 77 78
FEB — NOV (75M)
JAN → NOV (66M)
FEB → OCT (125M)
FEB → SEPT (100M)
FEB → OCT (100M)

F I G. 14.

Relationship between the spread of thermocline (M) and the stability below the thermocline in the area between Lat. 08°00'N and 17°00'N along the south-west coast of India during June-July-August (1974).



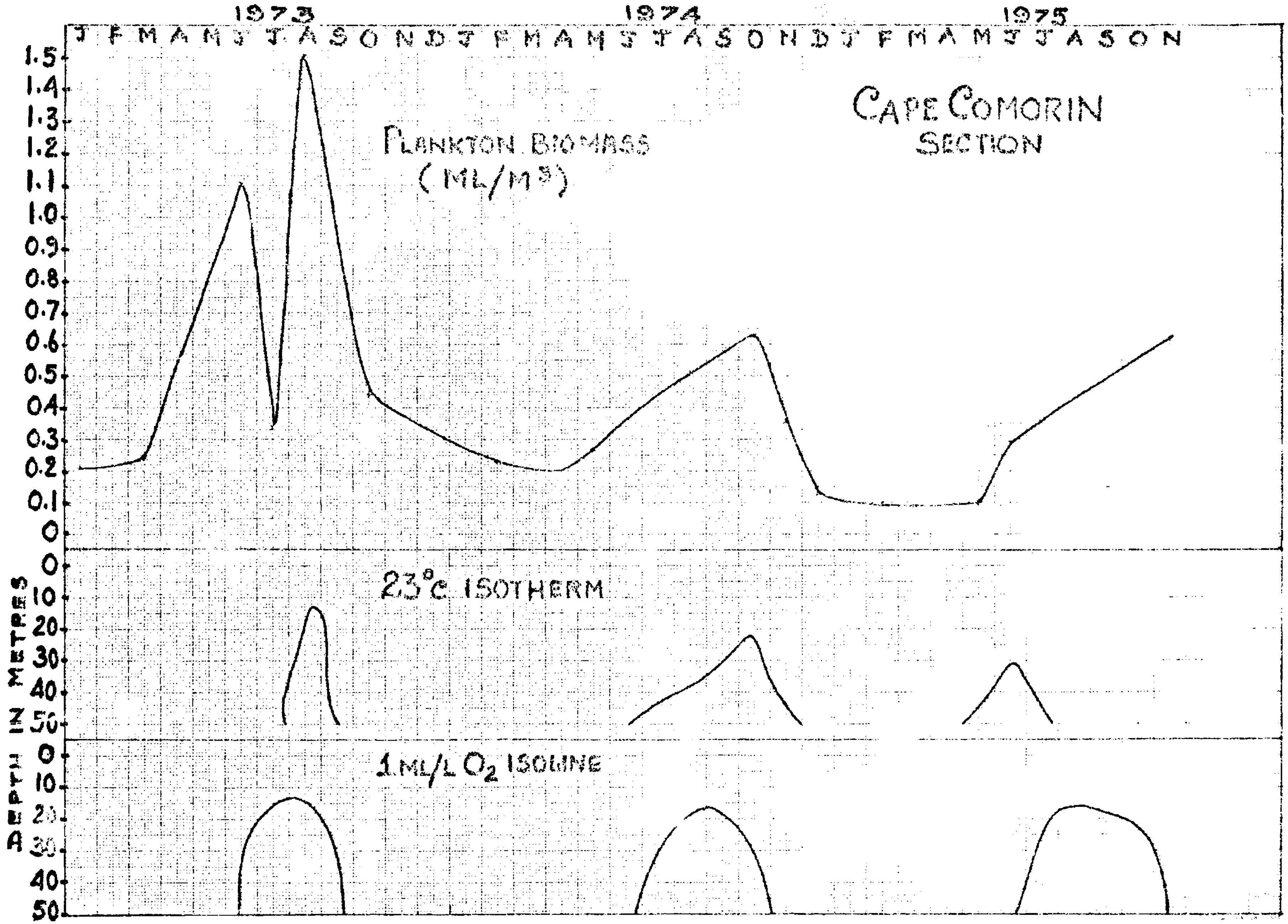
× Spread of thermocline (m)
170
160
150
140
130
120
110
100
90
80
70
60
50
40
LAT 08°00 N
09°00′
10°00′
11°00′
12°00′
13°00′
14°00′
15°00′
16°00′
17°00′N
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
● Stability below thermocline (10^-3 dσt / dz) × 10^8

Effect of upwelling on the fishery of the region:

Fig. 15A to F shows the correlation between the process of upwelling and zooplankton biomass at the different sections. The maxima for the plankton biomass always followed the peak periods of upwelling. Whereever the nutrient rich sub-surface water is brought upwards towards the sunlit surface levels by the process of upwelling, it provides the favourable environmental condition for the phytoplankton production followed by similar bloom in the zooplankton production. This time lag is dependent on factors such as incoming radiation and quantum of inorganic nutrients (nitrates, phostphates, silicates etc) readily available in the upwelled water to promote phytoplankton production. This interval varies from year to year and also from place to place. This would mean that the time lag would be more when the monsoon rain continues with a cloudy sky thereby reducing the incoming solar radiation. The nutrient content of the upwelled water would depend on the depth from which it has orginated and also the time taken by the watermass to reach the surface level. The plankton biomass curve for Cochin section showed maximum values during the months July-August during 1976, 1977 and 1978. The minimum values were observed during the months November-March. As regards upwelling indices and plankton biomass correlations, the phytoplankton/zooplankton biomass form the first step, as many of the commercially important pelagic fishes are plankton feeders. A careful evaluation of the intensity and duration of upwelling and the physico-chemical charecteristics of the upwelled water in a specific area will enable the

F I G. 15. A

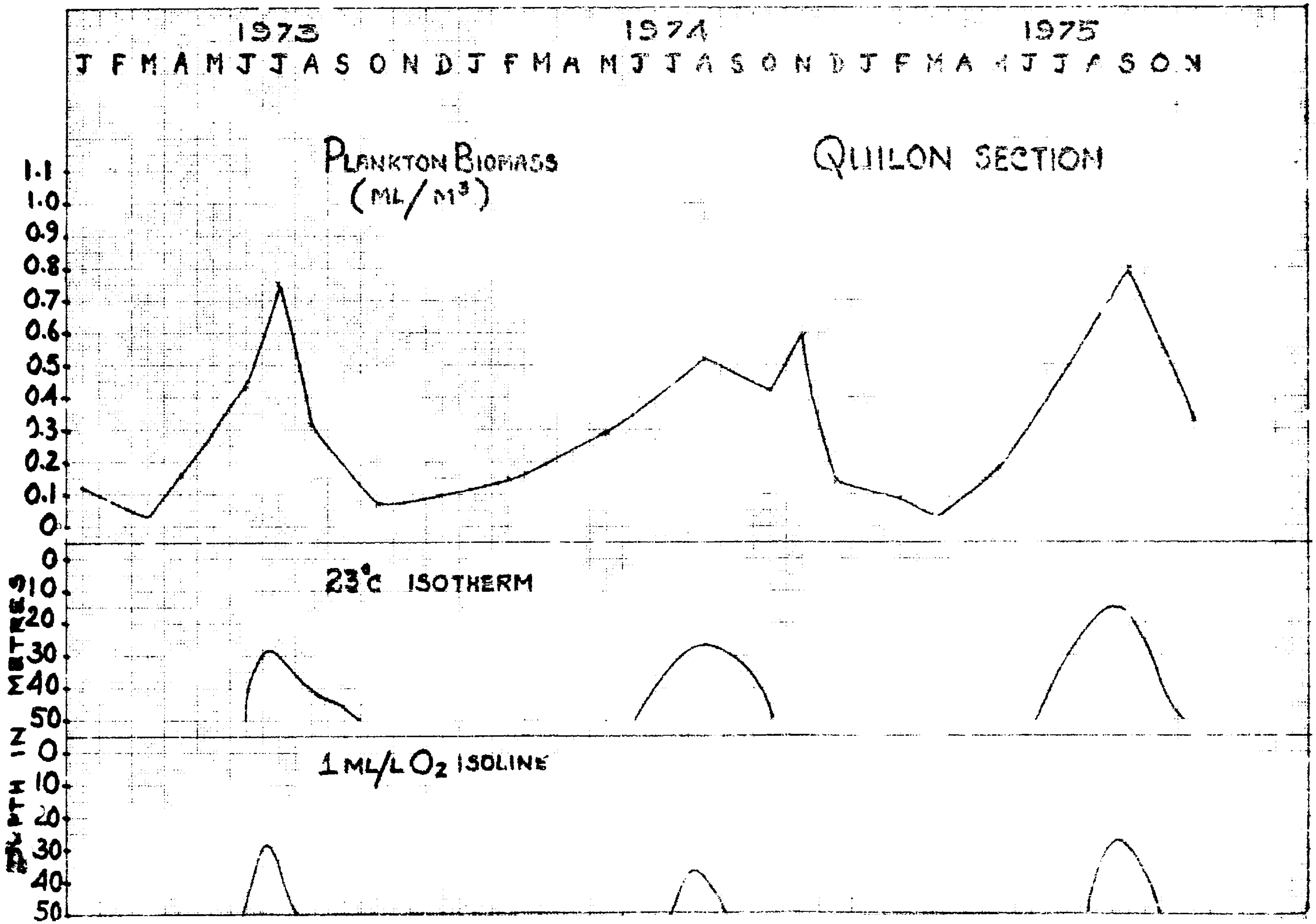
Relationship between the process of upwelling (in terms of vertical oscillation of 1 ml $O_2$/L isoline and 23°C isotherm) and plankton biomass off Cape-comorin (1973, 1974, 1975).



1973
1974
1975
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N
CAPE COMORIN
SECTION
PLANKTON BIOMASS
(ML/M3)
23°C ISOTHERM
1 ML/L O2 ISOLINE
DEPTH IN METRES
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
0
10
40
50

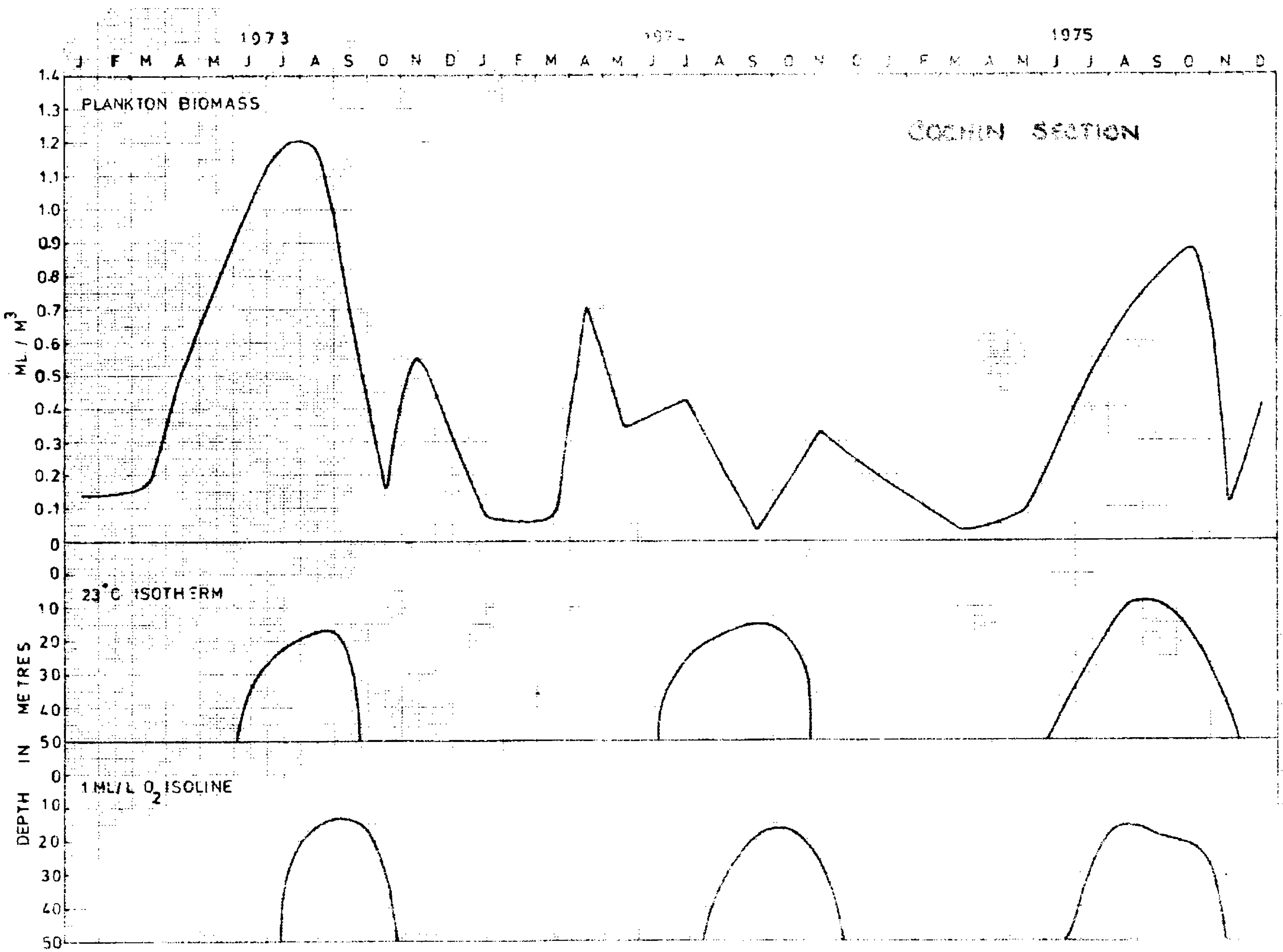
F I G. 15. B

Relationship between the process of upwelling (in terms of vertical oscillation of 1 ml $O_2$/L isoline and 23°C isotherm) and plankton biomass off Quilon (1973, 1974, 1975).


1973
1974
1975
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N
PLANKTON BIOMASS (ML/M³)
QUILON SECTION
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
23°C ISOTHERM
1 ML/L O2 ISOLINE
DEPTH IN METRES
0
10
20
30
40
50

F I G. 15. C

Relationship between the process of upwelling (in terms of vertical oscillation of 1 ml O2/L isoline and 23°C isotherm) and plankton biomass off Cochin (1973, 1974, 1975, 1976, 1977, 1978).


1973
1975
PLANKTON BIOMASS
COCHIN SECTION
ML / M3
23°C ISOTHERM
1 ML/L O2 ISOLINE
DEPTH IN METRES

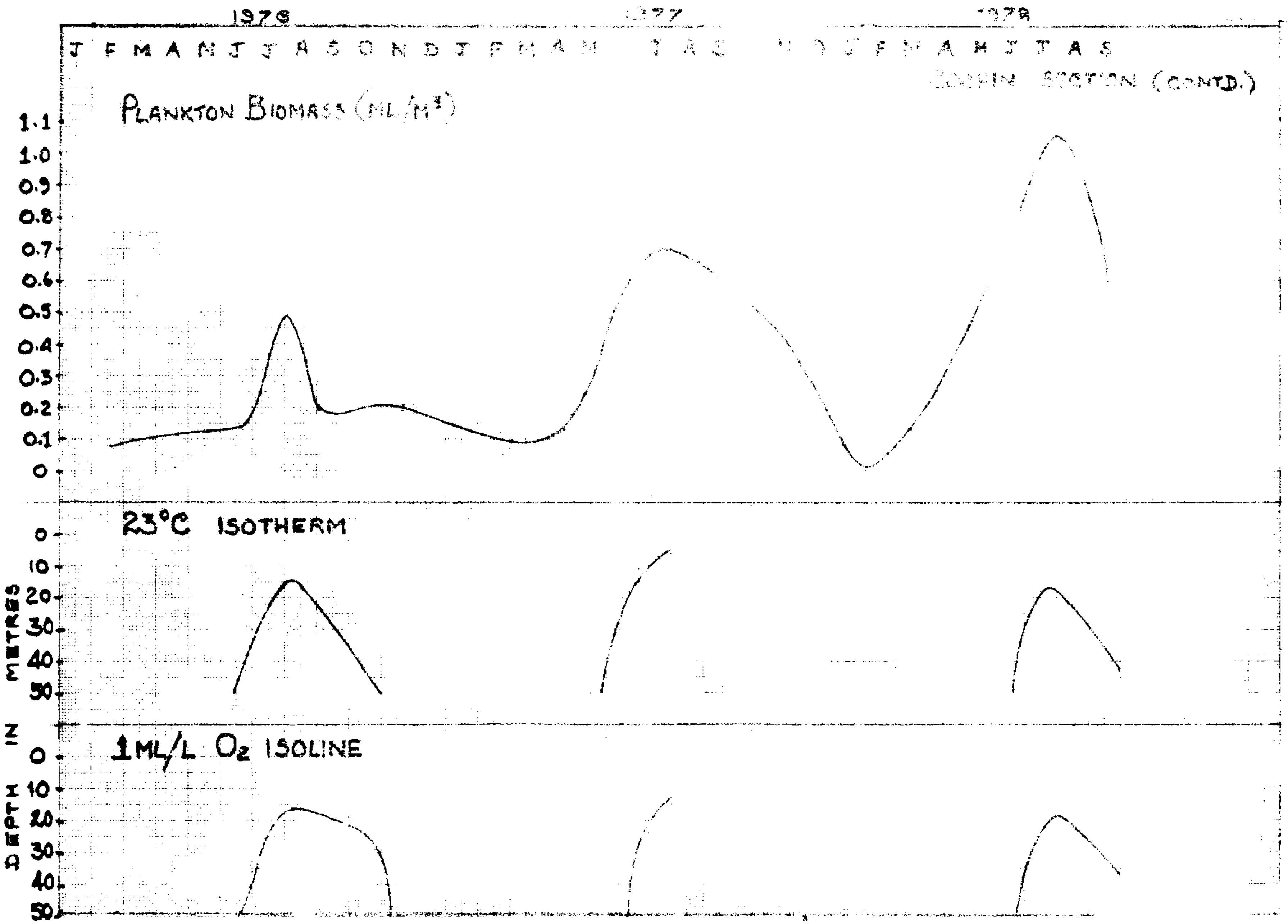
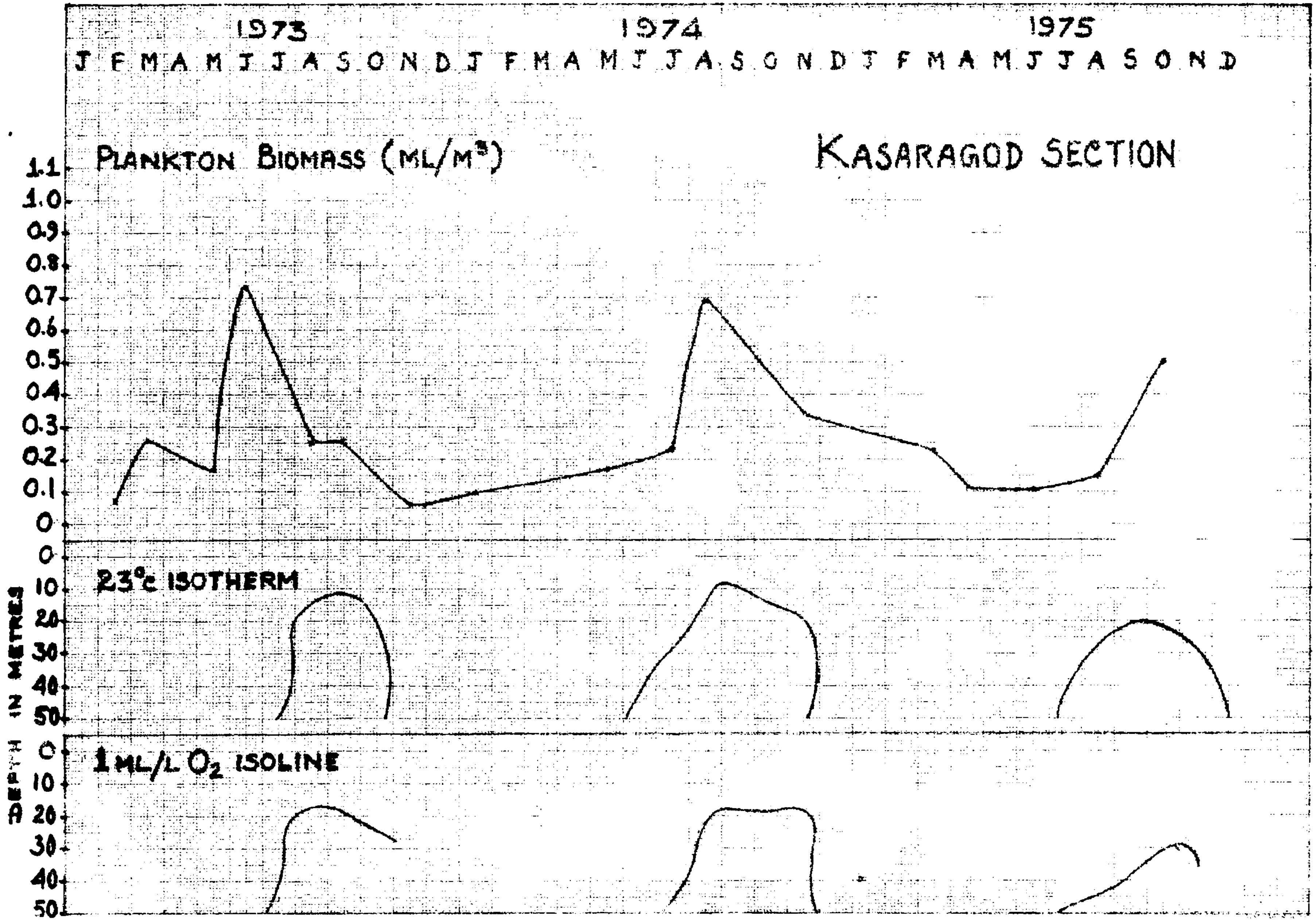

1976
1977
1978
J F M A M J J A S O N D J F M A M J A S N D J F M A M J J A S
STATION (CONTD.)
PLANKTON BIOMASS (ML/M³)
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
23°C ISOTHERM
0
10
20
30
40
50
1ML/L O2 ISOLINE
0
10
20
30
40
50
DEPTH IN METRES

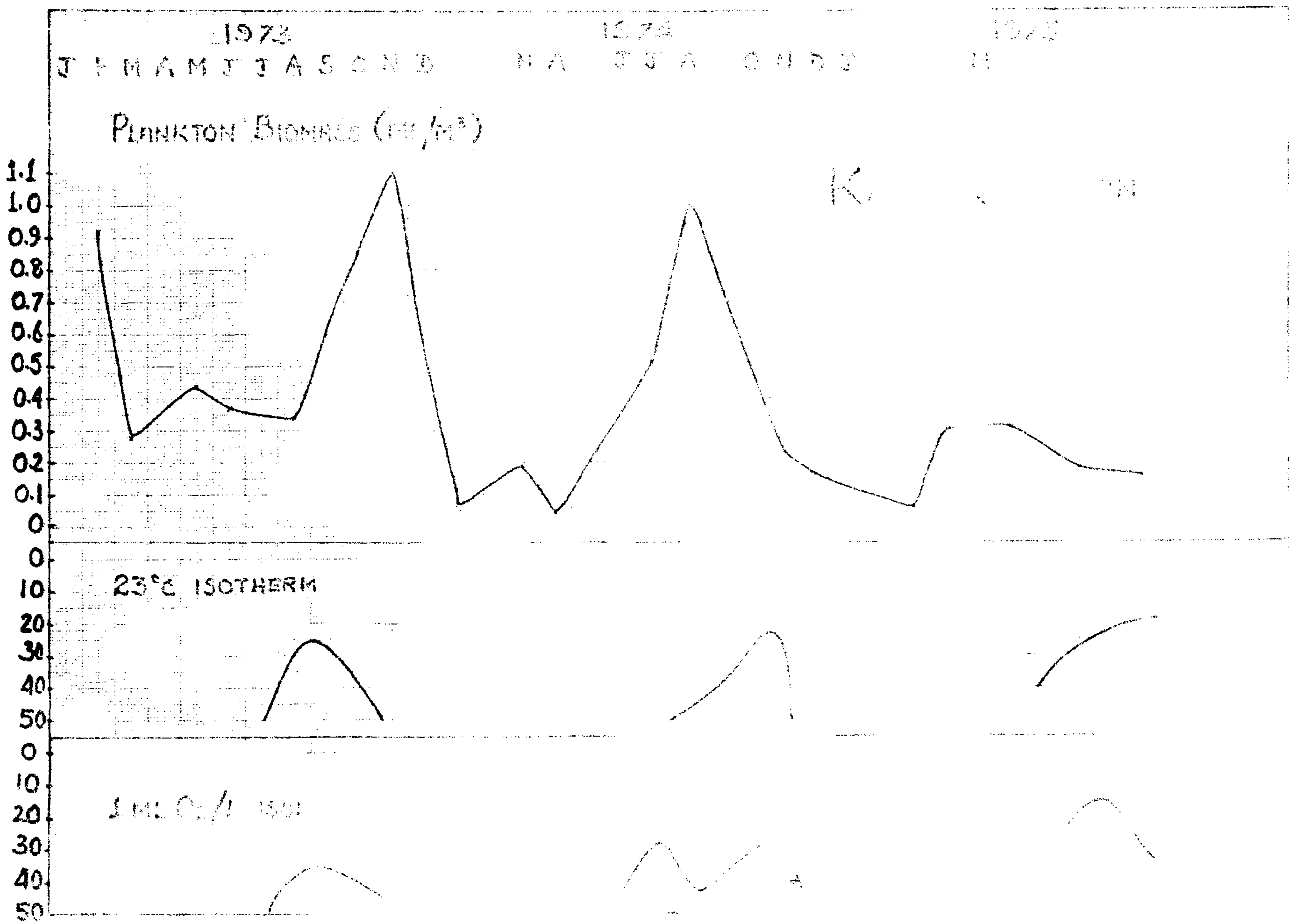
FIG. 15. D

Relationship between the process of upwelling (in terms of vertical oscillation of 1 ml $O_2$/L isoline and 23°C isotherm) and plankton biomass off Kasaragod (1973, 1974, 1975).


1973
1974
1975
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
PLANKTON BIOMASS (ML/M³)
KASARAGOD SECTION
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
23°C ISOTHERM
1 ML/L O2 ISOLINE
DEPTH IN METRES
0
10
20
30
40
50

F I G. 15. E

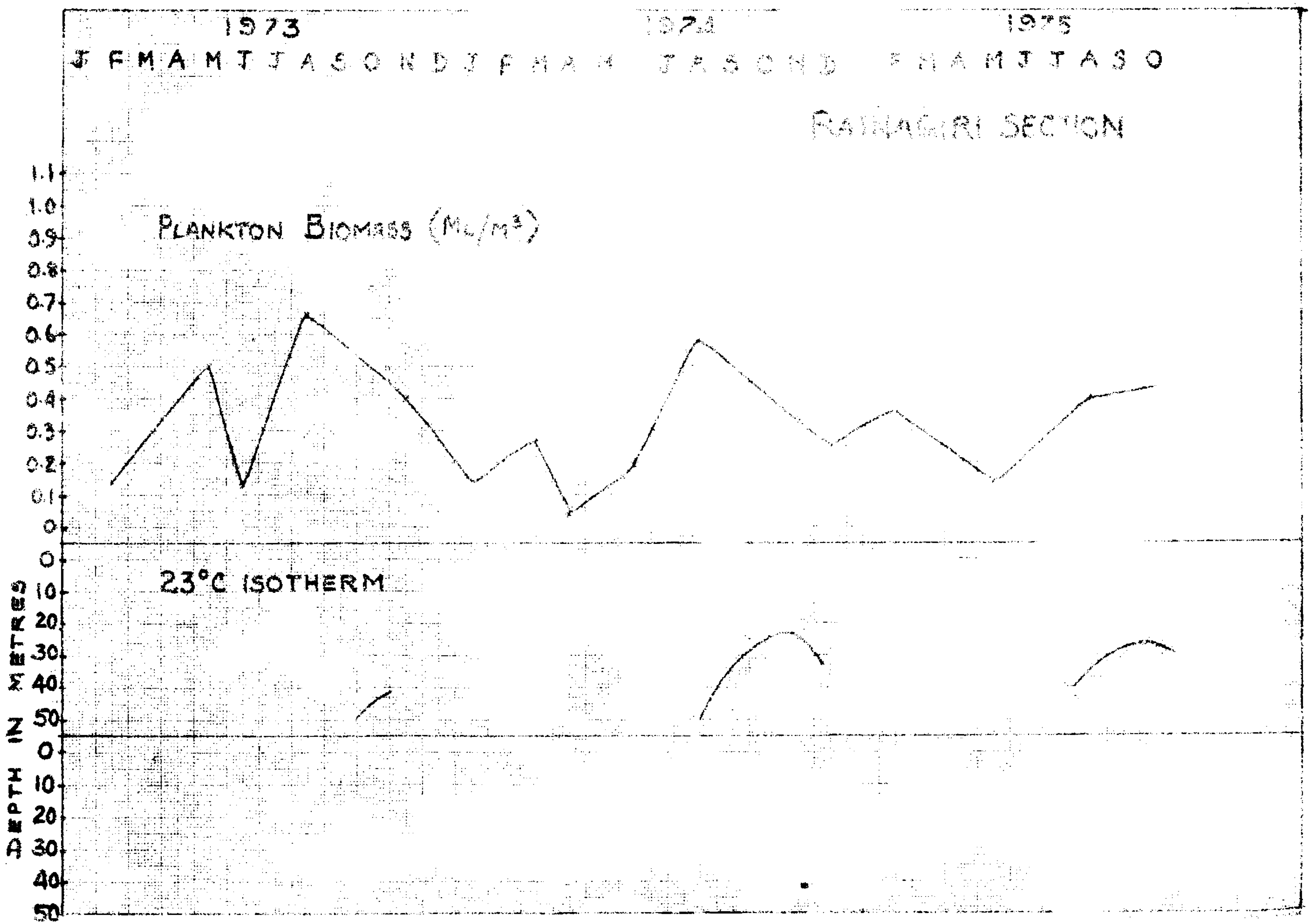
Relationship between the process of upwelling (in terms of vertical oscillation of 1 ml $O_2$/L isoline and 23°C isotherm) and plankton biomass off Karwar (1973, 1974, 1975 ).



1973
1974
J F M A M J J A S O N D
PLANKTON BIOMASS
23°C ISOTHERM
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
0
10
20
30
40
50

FIG. 15. F

Relationship between the process of upwelling (in terms of vertical oscillation of 1 ml $O_2$/L isoline and 23°C isotherm) and plankton biomass off Ratnagiri ( 1973, 1974, 1975).


1973
1974
1975
RATNAGIRI SECTION
PLANKTON BIOMASS (ML/M³)
23°C ISOTHERM
DEPTH IN METRES

prediction of the phytoplankton/zooplankton biomass and the possibilities of a good fishery especially for plankton feeding pelagic fishes sufficiently in advance.

In general, it was found that the zooplankton biomass was comparatively high in areas where upwelling was intense. During July- August 1978 the zooplankton abundance was very significant between Kasaragod and Karwar and the increase of the same was doublefold when compared to values observed during the July-August survey of 1977.

The effect of the upwelling process on the local fishery to a great extent depends on (1) the depth from which the upwelled water reaches the surface layers (2) the depth to which the sub-surface waters are brought up during the process of upwelling (3) the nutrient level of the upwelled water and the resultant phytoplankton/zooplankton activity (4) the vertical velocity of upwelling and (5) the period for which the upwelled water remains at the surface layers rataining its inherrent thermal, dissolved oxygen and nutrient characteristics.

Out of the above, except for nutrients, all other factors were considered while arriving at the deductions. Inspite of the high upwelling velocities observed for Quilon and Cape-comorin sections espectially during the year 1977 (Fig.12) supported by the other typical upwelling characteristics of comparatively low temperature, high density, low oxygen waters reaching the very surface, it was found that the plankton biomass at these sections did not indicate a proportionate increase during the following months. This was in sharp contrast to the condition in the Cochin and Kasaragod sections where a proportionate increase in the plankton biomass was observed following the peak upwelling season. Perhaps the difference observed might be due to the comparatively low nutrient level of the upwelled water which reached the surface levels both off Quilon and Cape-comorin. The sea bottom on the shallower areas of the continental shelf between Quilon and Cape-comorin is mostly rocky in contrast to the region north of Quilon where it is mostly muddy.

The surveys made by the Pelagic Fishery Project during the upwelling season have revealed the existence of pronounced oxygen minimum layers especially in areas between Quilon and Kasaragod. When the cool water of the thermocline with the associated oxygen minimum layer (0.5ml/L) normally found at depths of 100-150m, rises along the shelf, it is observed that part of the fish population moves in front of it into shallow surface mixed waters and part moves offshore, away from the centre of strong upwelling. However, at times, the rate of upwelling can suddenly be intensified and the replenishment of oxygen apparently slow down, which may lead to the mass mortality of fish in the particular area. Off the north-west coast of South America, upwelling is some times associated with the phenomenon known as ' El Nino '. This is due to the flow of warm tropical waters over the normally cold upwelled water to a variable distance down the Peruvian coast. The guano birds which live on the anchoveta of the area cannot dive below the warm water to reach the fish and they move down the coast to Chile, leaving all the young birds to die. The phenomenon produces a large scale change in the availability of anchoveta in these waters and may affect the year class of fish born in the following season.

Along the south-west coast of India, it was found that bulk of the pelagic fish population comprising of Indian mackerel, oil sardine and whitebait avoid temporarily areas of intense upwelling. Even with such temporary ill effects, upwelling is a blessing playing a great economic role by maintaining high fish production in these areas

Sinking:

Sinking phenomenon:

Sinking is the process in the sea whereby the surface waters are forced to sink towards sub-surface layers. Normally a similar downward movement is not possible as the density of sea water slowly increases with depth preventing any such vertical motion. Perhaps the only way by which a similar motion could be set in is by the presence of comparatively denser waters at the surface levels. Winter cooling which results out of a fall in the atmosperic temperature and also the evaporation at the surface lead to an increase in the density of the surface layers, thereby promoting the sinking motion. Converging current systems are also known to create conditions favourable for the formation of sinking, provided there is appreciable difference in the density characterstics of the two current systems. The sinking water masses slowly move down until they reach intermediate levels of more or less same density. Perhaps one of the advantages of the process of sinking is an increase in the vertical extent of the surface mixed layer with more or less uniform temperature and salinity characterstics. Since the process brings well aerated surface waters to the bottom levels, the dissolved oxygen content of the subsurface layers also shows a proportionate increase. This assumes great significance, especially with regard to the pelagic fish populations in the area as the process leads to an increase in the vertical extent of their habitat. Sinking caused by coverging current systems also lead to a concentration of plankton in the area where the process becomes active (Hela and Laevastu, 1962). Along the south-west coast of India, sinking has been reported by several authors in the past. According to Ramamirtham and Jayaraman (1960) sinking of the offshore waters (coastal convergence) occurs over the shelf during December and a well defined isothermal layer of about 75-100m thickness is present along the west coast. Sharma (1966), after conducting a detailed study of the thermocline characteristics concluded that along the south-west coast of India sinking is present from September to January.

Studies made by the author also indicated that the process of sinking is active in the area between Cape-comorin and Ratnagiri during the period September-February. It starts earlier in the south off Cape-comorin and Quilon. Off Cochin and Kasaragod the process begins during September and towards north, off Karwar and Ratnagiri during the months October/November. The process comes to an end earlier in the south (January) and later in the north (March). The phenomenon appears to be closely related to the cessation of the upwelling process and more or less follows the same trend from south to north. The vertical oscillation of the 23°c isotherm which shows the maximum movement on the vertical plane is taken as an indicator of the process of sinking. An approximate estimation of the velocity of sinking at the various sections during the year 1974 indicated that the velocities ranged between 79 and 139.5 cm/day. The maximum velocity of 139.5cm/ day was observed off Kasaragod and the minimum of 79 cm/day, off Ratnagiri. As in the case of upwelling, the sinking velocities also showed large variations from year to year and also from one area to another(Table-15).

Mechanism of sinking:

Under normal conditions the vertical stability of a water column will be high when the surface waters are less denser than the sub-surface waters. In areas where the prevailing meteorological/hydrographic conditions alter the above set up, the stability is affected and vertical mixing processes become active. In effect, the process of sinking is more or less opposite to the process of upwelling. In the case of the former, the process gets started at the surface layers where as in the latter the starting point is always somewhere below. Denser water moves along the vertical plane in favour of gravity in the former case (sinking) and against gravity in the latter case (upwelling). While the heavier sinking water is comparatively cold, and well aerated, the dense upwelled water is colder, highly oxygen deficient and rich in nutrient content.

The sinking water will spread more or less uniform temperature and dissolved oxygen conditions in the sub-surface layers. The

Table-15

Sinking intensity (based on the vertical movement of the 23°C isotherm)

| Section | Year | Period From | Period to | duration (days) | Downward movement from | Downward movement to | Vertical distance | Speed cm/day |
|---|---|---|---|---|---|---|---|---|
| Cape-comorin | 1973 | Jul | Jan | 193 | 57 | 140 | 83 | 43.0 |
| | 1974 | Oct | Jan | 96 | 43 | 125 | 82 | 85.4 |
| Quilon | 1973 | Jul | Jan | 195 | 20 | 140 | 120 | 61.5 |
| | 1974 | Sep | Jan | 123 | 23 | 140 | 117 | 95.1 |
| | 1975 | Aug | Feb | 185 | 21 | 80 | 59 | 31.9 |
| Cochin | 1973 | Sep | Jan | 125 | 17 | 140 | 123 | 98.4 |
| | 1974 | Aug | Jan | 142 | 16 | 150 | 134 | 94.4 |
| | 1975 | Sep | Jan | 134 | 17 | 150 | 133 | 99.3 |
| | 1976 | Aug | Apr | 262 | 18 | 115 | 97 | 37.0 |
| Kasaragod | 1973 | Aug | Mar | 224 | 24 | 119 | 95 | 42.4 |
| | 1974 | Sep | Dec | 86 | 30 | 150 | 120 | 139.5 |
| | 1975 | Sep | Mar | 182 | 35 | 90 | 65 | 35.7 |
| | 1976 | Aug | Nov | 93 | 19 | 108 | 89 | 95.7 |
| Karwar | 1973 | Oct | Mar | 151 | 47 | 133 | 86 | 57.7 |
| | 1974 | Oct | Jan | 93 | 34 | 150 | 116 | 124.7 |
| | 1975 | Oct | Jan | 92 | 35 | 130 | 95 | 103.3 |
| Ratnagiri | 1973 | Nov | Mar | 119 | 45 | 133 | 88 | 73.0 |
| | 1974 | Oct | Feb | 119 | 56 | 150 | 94 | 79.0 |

productivity of the area is also likely to show an increase as the phytoplankton get distributed in a larger volume of surface water within the euphotic zone. The sinking water, in general, has a higher density the further it is removed from the equator and will spread out at greater depths. Both cooling and evaporation at the surface levels increase the surface density which inturn set in a vertical convection current. The vertical extent of the convectiive motion would greatly depend on the density differences of surface and sub-surface layers.

Basically sinking is a vertical convective motion where the surface waters become denser and slowly sink to lower levels. The main causative factors are (1) surface cooling and the resulting increase in the density of the surface layers and (2) converging currents of differing density conditions. Along the south-west coast of India the effect of the first causative factor is likely to be more away from the equator. As regards the converging currents, the exact location of convergence may show variations from year to year depending on the velocity and density characteristics of the southward flowing high density Arabian sea water and the northward flowing less denser equatorial water. Perhaps the shifting of peak sinking area from year to year and from place to place is possibly originating out of these differences in the location of convergence zone. Table-15 gives the sinking characteristics of the shelf waters off the south-west coast of India ( the station at the edge of the continental shelf being chosen as the representative unit) as deducted from the vertical oscilations exhibited by the 23°c isotherm. The commencement, cessation, duration and intensity of the phenomenon for different years at the various sections have been estimated from the vertical time sections prepared for sea water temperature. Convergence zones can be identified with the help of horizontal surface salinity charts where marked variations in the surface salinity values are indicative of the process of sinking reulting out of converging currents (Fig. 2, 3 and 4).

Effect of sinking on hydrographic conditions:

The most important change which is brought about by the process of sinking on the hydrographic conditions is the increase in the vertical extent of the surface mixed layer. The sub-surface layers of the sea become warmer and more aerated. The thermocline which is found at the very surface during the south-west monsoon season is shifted towards deeper waters. In general instability is noticed at the surface levels during the sinking period. Murthy (1965) also found the average thermocline depth along the south-west coast of India to be deepest during winter. In fact some of the benefits of the upwelling process are derived during the sinking season. This is especially true with regard to the high nutrient content of the upwelled water and the resultant plankton bloom which occurs during the sinking period. The process of sinking also warms up the surface layers because of the spreading of the northward flowing equatorial surface water which increases the depth of the surface mixed layer and also the dissolved oxygen concentrations at the sub-surface levels. Perhaps the reversal of the current system at the surface levels along the south-west coast from southerly to northerly form the very basis of the sinking phenomenon and the associated changes in the hydrographic conditions. In fact the convergence zones develop out of the northerly current which gets established by October/November . The winter cooling is found to be more effective towards northern latitudes where an appreciable fall in the atmospheric temperature is noticed during this period. Another factor which assumes great significance is the reduction in the fresh water supply through rains and river runoff which in turn leads to an increase in the surface salinity values characteristic of the waters during the post-monsoon season

Convergence zone:

The existence of a convergence zone in the area under observation is evident from the horizontal salinity gradients observed during the period January-March (Fig.2,3,and 4). In 1974 the sea surface salinity increased from 33‰ to 35‰ between Karwar and Ratnagiri sections. This difference was less pronounced in 1975 at more or less the same location. In 1973 a similar zone was present between Kasaragod and Calicut ($12^{0}$ -$11^{0}$N Lat.). The variations of surface salinity suggests that the convergence zone exhibits seasonal variations spreading northwards with the intensity of the northerly flow which carries equatorial surface water (Darbyshore, 1967 ) towards northern latitude During the south-west monsoon season, the salinity distribution at the surface levels is not indicative of the convergence mainly due to the rainfall and runoff effects.

Effect of sinking on the Fishery of the region:

The period of peak sinking activity along the south-west coast (October-March) very well coincide with the peak fishing season for two of the major commercially important pelagic fishes of the area viz. oil sardine and mackerel. The warming up of the surface water from the low temperature conditions of the upwelled waters, brought about by the influence of the warm equatorial waters being carried northward in the northerly current provide the necessary favourable temperature conditions. The sinking of surface waters result in an increase in the vertical extent of the surface mixed layer with comparatively high oxygen and nutrient concentrations. Thus, as regards the pelagic fishes are concerned, their favourable habitat get extended vertically. According to Ramamirtham and Jayaraman (1960), in December, sinking of the offshore water (coastal convergence) occurs over the shelf and a well defined isothermal layer of about 75-100m in thickness is present along the west coast of India. It is also known that convergences lead to a concentration of zooplankton (Hela and Laevastu, 1970). It has been also pointed out by Noble (1972) that zooplankton dominates in the food of oil sardines. Hence it is quite likely that the oil sardine concentrates in areas of zooplankton abundance which in turn is related to the phenomenon of convergence along the coast. It is possible that both mackerel and oil sardine move along with the northward flowing current which in turn produces convergence zones where there is possibility for accumulation of zooplankton.

In the case of white bait it is found that the northerly migration of the fish starts by early November. The setting up of the northerly current with the post-monsoon conditions prevailing along the south-west coast viz. comparatively higher oxygen concentrations, the plankton bloom which followed the upwelling and the gradual rise in the sea water temperature resulting from the recession of the upwelling process provide the fish (white-bait) with the favourable environmental conditions. By December, the distribution of whitebait spreads almost all along the south-west coast (between Tuticorin and Ratnagiri). During both southward and northward migrations exhibited by the fish, the prevailing surface currents also favour the passive floating and drifting. The phytoplankton as well as zooplankton bloom which become effective during the sinking season also provide these fishes with the required food. According to Murthy (1965) the catches for oil sardine and mackerel are maximum during the winter season (period of sinking) when the northerly drift gets established along the south-west coast and it is quite possible that the fishery is directly or intimately related to the coastal drift.

There had been attempts in the past to correlate the oil sardine and mackerel fishery with rainfall. Normally, the bulk of the oil sardine catch was landed following the period of heavy rainfall during the south-west monsoon season. The oil sardine fishery at Ullal (Prabhu et al., 1972) on the other hand was lowest (52.1t) in 1963-1964 when the rainfall was heaviest (306.5cm). The catches were better during 1965-1966 and 1966-1967 (283.7 t and 385.6 t respectively) when the annual rainfall was comparatively low (274.1 cm and 283.6 cm respectively) Pradhan and Reddy (1962) on the otherhand found an inverse correlation between annual rainfall and mackerel catches off Calicut. They have also reported that high temperature and salinity affect the mackerel fishery adversely. The mackerel season in North Kanara coast coincided with the transition period from the low salinity and temperature conditions during the south-west monsoon period to the high salinity and warmer conditions of summer (Ramamurthy, 1965).

Organic Production

All marine life, including fishes, are sustained by organic production, the fixation of carbon by small, microscopic floating and drifting plants occuring in the euphotic zone, the phytoplankton. The products of photosynthesis viz. carbohydrates, oil, fats, proteins, vitamins etc. are consumed by minute floating and drifting animals, the zooplankton, which in turn are eaten up by larger ones and so on at different trophic levels.

As has been already prointed out, the process of upwelling enriches the euphotic zone leading to a phytoplankton bloom after a certain lapse of time and away from the area where the upwelled water reaches the surface levels. The area of concentration normally depends upon it's desplacement by ~~by~~ the direction and velocity of surface currents. According to Menon (1945), on the west coast of India the bloom of phytoplankton during the south-west monsoon is noticed off the

Trivandrum coast from January onwards reaching a peak in May. Further north, off Calicut and northwards the peak is attained in July-August. This would indicate the commencement of upwelling at subsurface levels much earlier even when the current is northerly along the west coast. From September onwards the phytoplankton bloom vanishes. This would indicate the cessation ofupwelling from there on (Subramonyan, 1973).

Distribution of different groups of planktonic organisms varies greatly depending on their place in the food chain; the higher the trophic level they occupy, the further they are removed in space and time from areas of enrichment (Vinogradov and Voronina). By the time the predators attain their population maximum in the sequence of biological events in the sea, they may be located quite some distance away from the centre of upwelling. Rao and Nair (1973) have shown that chaetognaths are exclusively carnivores and occupy the tertiary level in the food chain. Naturally areas of maximum chaetognath population can be expected to be located away from the upwelling areas. Previous studies on the chaetognaths of Indian Ocean (Vijayalakshmi, 1969) also indicated that population maxima during the south-west monsoon period are not adjacent to the upwelling region but shifted towards the fringe of the enriched area.

Cushing (1971) in his comprehensive review of the upwelling areas in the world oceans has discussed at length the production cycle in the upwelling systems. According to him the peak production reaches the surface not far from the centre of upwelling and the plant and animal populations move away from the centre of upwelling.

Primary production in the area under study:

Nair et al. (1973) have reported on the organic productivity at selected stations off the west coast of India, within 50m, in terms of carbon production beneath a square metre of the sea surface (Table-16). The average productivity values for all the stations observed within 50m depth comes to 1.19 gc/m$^2$/day equivalent to an annual gross production of 434 gc/m$^2$/year which is quite high compared to several other areas of the world as can be seen from Table-17. It has been observed that the level of production is more towards the coast and less towards the edge of the continetal shelf and least outside the shelf. Beyond 50m., the mean value of primary production is found to be 0.43gc/m$^2$/day, with an annual net production of 25gc/m$^2$/year. Based on these carbon production values and the known yield rates in intensively exploited areas in other parts of the world, it is estimated that 1,200,000 tons of fish could be harvested from the area within 50m depth of the west coast (Nair et al. 1973). This figure is almost double that of the present yield from the area. An additional quantity of 500,000t. yield is computed for the area outside the 50m. depth coutour up to the shelf edge. A summary of primary production values in gc/m$^2$/day for the different state/depth zones of the area under study given by Nair et al (1973) is reproduced in Table-18.

Table-16

**Values for daily primary production at some stations along the west coast of India expressed as grams carbon fixed beneath a square metre of sea surface. (Within 50 metres depth) - Nair et al 1973**

| Date | Position: Latitude N | Position: Longitude E | Depth in metres | Production $gC/m^2/day$ |
|---|---|---|---|---|
| 5 . 6 . 1965 | 8°00' | 77°20' | 38 | 2.09 |
| 15 . 12. 1965 | 13°25' | 75°10' | 40 | 0.95 |
| 16 . 12. 1965 | Karwar Bay | | 7 | 1.39 |
| 3.. 2 . 1966 | 9°40' | 76°00' | 40 | 0.18 |
| 6 . 9 . 1966 | 9°00' | 76°[illegible]' | 25 | 1.24 |
| 7 . 8 . 1967 | 14°08' | 74°18' | 30 | 0.61 |
| 6 . 9 . 1967 | 9°52' | 76°10' | 18 | 2.37 |
| 7 . 9 . 1967 | 9°20' | 76°51' | 50 | 1.18 |
| 7 . 9 . 1967 | 8°42' | 76°35' | 35 | 1.26 |
| 9 . 9 . 1967 | 7°45' | 77°19' | 50 | 0.48 |
| 9 . 9 . 1976 | 7°45' | 78°00' | 47 | 1.43 |
| 20 . 7 . 1968 | 8°53' | 76°21' | 50 | 1.12 |
| 21 . 7 . 1968 | 10°29' | 75°51' | 37 | 0.89 |
| 22 . 7 . 1968 | 11°19' | 75°36' | 28 | 1.34 |
| 24 . 7 . 1968 | 12°08' | 74°58' | 37 | 2.45 |

Table-17

Annual primary productivity (gross) in certain marine environments as grams carbon per square metre of sea surface

(Nair *et al* 1973)

| Locality | Production $gC/m^2/year$ | Reference |
|---|---|---|
| Barents Sea | 170 - 330 | Kreps and Verjbinskaya 1932 |
| English Channel | 60 - 98 | Cooper, 1933 |
| Georges Bank | 309 | Riley, Stommel and Bumpus, 1949 |
| North Sea | 57 - 82 | Steek, 1956 |
| Long Island Sound | 470 | Riley, 1956 |
| Off Hawaii (open ocean) | 21 | Doty and Oguri, 156 |
| Off Hawaii (inshore) | 123 | - do - |
| Turtle grass bed (Florida) | 4650 | Odum, 1956 |
| Hawaiian coral reef | 2900 | Kohn and Helfrich, 1957 |
| Shelf waters off New York | | |
| Shallow coastal region | 160 | Ryther and Yentsch, 1958 |
| Continental slope | 100 | Ryther and Yentsch, 1958 |
| North Central Sargasso Sea | 78 | - do - |
| Gulf of Mannar (inshore within 10 depth) | 745 | Prasad and Nair, 1963 |
| Temperate oceans | 100 - 150 | Strickland, 1965 |
| Equator | 110 - 146 | - do - |
| Barren tropical oceans | 50 | - do - |
| West Coast of India (within 50 m depth) | 434 | Nair *et al* 1973 |
| East coast (Continental shelf) | 230 | - do - |

Table-18

Summary of primary production values for different zones along the west coast of India in $gC/m^2$/day (Nair et al 1973)

| States | Upto 50 m | | | 50 to 200 m | | | 200 m | | |
|---|---|---|---|---|---|---|---|---|---|
| | No.of stns. | Total | Average | No.of stns. | Total | Average | No. of stns. | Total | Average |
| Madras (West Coast) | 3 | 4.00 | 1.33 | 4 | 1.49 | 0.37 | 6 | 1.08 | 0.18 |
| | | | | ( 1 | 4.55 | 4.55 ) | | | |
| Kerala | 10 | 12.17 | 1.22 | 13 | 3.20 | 0.25 | 22 | 3.80 | 0.17 |
| Mysore | 6 | 6.50 | 1.08 | 4 | 0.77 | 0.19 | 3 | 0.84 | 0.28 |
| Maharashtra | -- | -- | -- | 2 | 0.23 | 0.12 | -- | -- | -- |
| | 19 | 22.67 | 1.19 | 24 | 5.69 | 0.43 | 31 | 5.72 | 0.18 |

Zooplankton:

The zooplankton productivity showed a close relationship with monsoon and the associated upwelling. The west coast is mainly influenced by the south-west monsoon where as the Gulf of Mannar is influenced by both south-west and north-wast monsoons.

In the main upwelling area on the west coast, between Kasaragod and Quilon, the peak of zooplankton abundance occurs in July-August period with another peak during October-December. The latter period was also the peak period for the northern regions, off Karwar and Ratnagiri. In the Gulf of Mannar, highest productivity was observed in July and in November-December period.

The correlation between the process of upwelling (shown in the upward movement of 23$^{o}$c isotherm and 1 ml/L $O_2$ isoline) and zooplankton biomass (displacement volume ml/m$^3$) observed off Cape-comorin, (1973-1975), Quilon (1973-1975), Cochin (1973-1978) Kasaragod (1973-1975), Karwar (1973-1975) and Ratnagiri (1973-1975), is presented in Figures: 15A to 15F. The pattern which has emerged out clearly indicate a close relationship between upwelling and plankton production in the area under study.

Ichthyoplankton was most abundant from May to September, with a peak in July-September period, moderate in October and November and low from December to April.

Sardine larvae were found all year round but mostly between June and August. Main spawning ground seemed to be between 8°N and 10° 30'N on the middle and outer shelf in a 10-15n. miles band, 20n. miles off-shore (40-80m). Moderate spawning activity of this group of fish was also registered south of Quilon and south-east of Tuticorin.

Mackerel seems to have more extended spawning season than sardine. High density of mackerel larvae were found in April, July, August and November. On the other had, neither eggs nor larvae of this species were found in January, March and December. Main spawning ground is believed to be between 8°and 15°N Lat. in a 10n. miles belt (mostly between 55 and 100m depth) with most larvae observed off Cochin and Karwar.

The major part of whitebait ichthyoplankton was found between April and August in the waters above 20-60m. In the central area, between Quilon and Kasaragod (7°30'-11°N) the peak spawning occurred in May-July period, whereas south of Quilon and off Cape-comorin this happend in October-November period.

The average plankton biomass values ($ml/m^3$) in the midshelf (3rd stations from the coast) for the different sections during theperiod 1971-1978 is given in Table-19. Menon and George (1977) after conducting a study on the abundance of zooplankton along the south-west coast of India during the period 1971-1975 reported a recurring pattern in the zooplankton abundance and distributions in the shelf waters. In general the period from July to September was found to be the time of peak plankton production, with a fairly uniform concerntration of plankton beyond

**Plankton biomass values (ml./m$^3$) in the midshelf (3rd station from the coast) in space and time (Source : PFP records)**

| Section | | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|
| Ratnagiri | H | - | 0.87(Aug.) | 0.66(Aug.) | 3.58(Aug.) | 0.43(Oct.) 0.40(Aug.) | 0.83(May) | 0.83(Dec.) | - |
| | L | - | 0.35(Dec.) | 0.13 (Jun.) | 0.04(Apr.) | 0.14(May.) | - | 0.13(Jul) | 0.33(Jun.) |
| Karwar | H | 1.44(Oct.) | 1.75(Sept.) | 1.10(Nov.) | 1.02(Aug.) | 0.31(Jun.) | 1.87(Aug.) | 0.73(Dec.) | 1.02(Jun.) |
| | L | - | 0.01(Dec.) | 0.28(Mar.) | 0.04(Apr.) | 0.16(Oct.) | 0.12(Apr.) | 0.22(Jul.) | - |
| Kasaragod | H | 0.55(Sept.) | 0.93(Jul.) | 0.73(Jun.) | 2.72(Dec.) | 0.50(Oct.) | 0.19(Jul.) | 0.57(Jul.) | 0.43 (Aug.) |
| | L | 0.20(Nov.) | 0.02(Dec.) | 0.06(Nov.) | 0.10(Jan.) | 0.11(Apr.) Jun. | 0.06(Apr.) | - | - |
| Cochin | H | 1.25(Sept.) | 4.85(Sept.) | 1.20(Jul. Aug.) | 1.70(Feb.) | 0.88(Sept.) | 0.34(Aug.) | 0.69(Jul.) | 1.05(Jul.) |
| | L | 0.07(Oct.) | 0.06(Jul.) | 0.14(Jan.) | 0.03(Sep.) | 0.03(Mar.) | 0.12(Apr.) | 0.09(Mar.) | 0.08(Jan.) |
| Quilon | H | - | 0.37(Sep.) | 0.75(Jul.) | 0.59(Nov.) | 0.80(Sep.) | 1.16(Aug.) | 1.12(Jul.) | 1.15(Jul.) |
| | L | 0.05(Dec.) | 0.04(Apr.) | 0.03(Mar.) | 0.14(Dec.) | 0.03(Mar.) | - | - | - |
| Cape Comorin | H | - | - | 1.60(Aug.) | 0.63(Oct.) | 1.62(Nov.) | 0.34(Nov.) | 0.93(Jul.) | 0.43(Jul) |
| | L | - | - | 0.21(Jan.) | 0.20(Apr.) | 0.09(Mar.) | 0.19(Jun.) | 0.06(Nov.) | - |

H- Highest monthly average.

L- Lowest monthly average.

the nearshore waters all along the coast. Thereafter until December a shoreward shift of the concentration was evident, especially in the south. At the same time the continuous distribution broke up, became patchy and the overall abundance was greatly reduced and reached the lowest level in January and February. They also found that the biological cycle was clearly influenced by the process ofupwelling especially in the central and southern region.

Fishery in the area under study:

The area chosen for the study comprises of the south-west coast from Ratnagiri (lat. 17°N) down to the south-east coast upto Tuticorin (Lat. 9°N) including the coasts of southern Maharashtra, Goa, Karnataka, Kerala and south-west and south-east coasts of Tamilnadu.

The estimates of marine fish landings in the country, for each maritime state, the species-wise composition and effort expended in obtaining the catch etc. are published by the Central Marine Fisheries Research Institute at Cochin every year. These estimates were made use of in the preparation of statistical review which is based on the catch statistics relating to the ten year period of 1968-1977. The pattern of landings in the area under study only in relation to the all India landings, are considered here. Regarding the states of Maharashtra and Tamilnadu, though only parts of the states come under the area, the landings for the entire state are considered here as the figures for the respective parts of the states are not available.

Total marine fish catch

The annual landing figures for the entire country and for the individual states under reference for the period 1968-1977 are given in Table-20. During this period, the total catch can be seen to be fluctuating, though not very widely. The average annual catch for the period was 1,154,051 tonnes and the corresponding figures for the five states and the percentage contribution to the total fish landings (All India) were as follows:

| State | 1968-1977 Average catch (tonnes) | Percentage of All India landings |
|---|---|---|
| Tamil Nadu | 178,262 | 15.5% |
| Kerala | 373,935 | 32.4% |
| Karnataka | 92,290 | 8.0% |
| Goa | 26,141 | 2.3% |
| Maharashtra | 214,663 | 18.6% |

As a single state, the contribution of Kerala to the total fish landings of the country is maximum. The year 1975 recorded the maximum catch of 1.42 million tonnes for the whole country while the minimum recorded was 0.91 million tonnes in 1969. The year 1972 has recorded a steep decline from 1971 compared to other years. However, Table: 20

**Total Marine fish landings: All India and statewise 1968-'77**

(Figures in tonnes)

| | Tamilnadu | Kerala | Karnataka | Goa | Maharashtra | All India |
|---|---|---|---|---|---|---|
| 1968 | 154,400 | 345,301 | 87,822 | 18,888 | 123,916 | 934,611 |
| 1969 | 151,876 | 294,787 | 75,793 | 27,559 | 168,720 | 913,630 |
| 1970 | 149,106 | 392,880 | 115,205 | 20,736 | 192,361 | 1,077,466 |
| 1971 | 160,619 | 445,347 | 103,724 | 39,980 | 215,305 | 1,161,389 |
| 1972 | 155,153 | 295,618 | 92,676 | 30,104 | 220,002 | 980,049 |
| 1973 | 182,419 | 448,269 | 91,484 | 15,740 | 226,696 | 1,220,240 |
| 1974 | 175,713 | 442,257 | 76,263 | 19,534 | 184,961 | 1,217,797 |
| 1975 | 221,215 | 420,836 | 87,494 | 29,170 | 256,619 | 1,422,693 |
| 1976 | 226,078 | 331,047 | 95,283 | 34,968 | 293,601 | 1,352,855 |
| 1977 | 206,046 | 355,037 | 97,152 | 24,730 | 264,452 | 1,259,782 |

Source: Central Marine Fisheries Research Institute, Cochin.

1973 has shown good improvement and the decline was considerably offset by an increase over the year 1972. The year 1975 has shown vast improvement over the previous years, though 1976 and 1977 have shown declines from the previous years.

Oil Sardine:

Oil Sardine, represented by the species Sardinella longiceps, val. has an important share in the total marine fish landings. The average annual landings were 1,78,940 tonnes contributing 15.5% to the total marine fish catch. It is a highly fluctuating fishery and Kerala and Karnataka are the most important states for this fishery. In 1971 the highest sardine catch (1,94,977 t) was made contributing 93.17% to the all India oil sardine production.

In 1977, of the Country's total oil sardine catch, 78.17% came from Kerala state alone. On an average 38.5% of landings in Kerala and 33.6% in Karnataka comprised of Oil Sardine. The average landings of this fish in Kerala and Karnataka were 144,151 tonnes and 31,015 tonnes respectively and together they accounted for 98% of the total oil sardine landings of the country. Thus the contribution from other states to this fishery is negligible.

Quarter-wise landings of oil sardine in Kerala and Karnataka during the period 1968-1978 is given in Table-21. The year 1968 was a peak period for this fishery with a total landingsof 301,641 tonnes. In the following year, there was heavy decline of 127 thousand tonnes while

Oil Sardine: Quarterwise landings in Kerala and Karnataka 1968-'78

(Figures in tonnes)

| Year | Kerala | | | | Karnataka | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| 1968 | 47,319 | 4,213 | 57,895 | 137,621 | 1,859 | 12 | 100 | 51,756 |
| 1969 | 34,655 | 5,374 | 14,988 | 84,966 | 16,732 | 94 | 309 | 16,443 |
| 1970 | 30,986 | 27,244 | 46,981 | 86,472 | 19,424 | 316 | 415 | 13,676 |
| 1971 | 86,150 | 7,317 | 19,378 | 82,1B2 | 7,568 | 42 | 49 | 4,177 |
| 1972 | 40,907 | 21,566 | 11,710 | 30,243 | 4,624 | 235 | 354 | 10,197 |
| 1973 | 27,884 | 20,701 | 18,963 | 55,285 | 6,966 | 652 | 258 | 7,619 |
| 1974 | 18,594 | 20,623 | 15,269 | 47,649 | 14,305 | 488 | 579 | 5,412 |
| 1975 | 41,666 | 15,944 | 12,404 | 27,169 | 11,150 | 502 | 16 | 41,033 |
| 1976 | 29,078 | 19,749 | 9,173 | 65,937 | 35,636 | 746 | 978 | 4,091 |
| 1977 | 22,033 | 20,620 | 17,084 | 57,619 | 4,387 | 425 | 842 | 25,491 |
| 1978 | 17,873 | 7,509 | - | - | 19,389 | 1754 | - | - |

Source: Central Marine Fisheries Research Institute, Cochin.

there was some improvement in the year 1970. The year 1972 has also seen a heavy decline of about 82 thousand tonnes. In the rest of the years the total landings remained with less fluctuations.

<u>Seasonal aspects of oil sardine fishery</u>:

The average quarter-wise catch (tonnes) of oil sardine for the states of Kerala and Karnataka were as follows:

| | Kerala | Karnataka |
|---|---|---|
| First Quarter (January-March) | 37,927 (26.3%) | 12,285 (39.6%) |
| Second Quarter (April-June) | 16,335 (11.3%) | 351 (1.1%) |
| Third Quarter (July-September) | 22,384 (15.5%) | 390 (1.3%) |
| Fourth Quarter (October-December) | 67,509 (46.9%) | 17,990 (58.0%) |

The figures in brackets give the landings of each quarter as percentage of annual average landings. From the above it is clear that the first and fourth quarters are the most important for this fishery, especially in Karnataka.

The second and third quarters relating to the period April to September, have landed 26.8% in Kerala and only 2.4% in Karnataka.

While in certain years first quater has landed more than the fourth quarter, in other years the reverse is the case. Thus it cannot be exclusively established which of the two quarters is more productive.

Mackerel:

Next in importance to oil sardine in the area under study is the fishery for mackerel, Rastrelliger kanagurta (Cuvier). It's average landings were 85,516 tonnes contributing 7.4% to the total marine fish catch. Kerala and Karnataka, once again, are the most important states for this fishery followed by Goa and Maharashtra ( in Maharashtra the southernmost part of the state which is included in the area under study is the only mackerel landing area of the state) Like oil sardine the fishery for mackerel also shows considerable fluctuations. The year 1971 was a peak year for this fishery with a total landing of 204,600 tonnes. The states of Kerala, Karnataka and Goa also recorded maximum annual landings in this year. The year 1968 recorded the minimum catch of 21,700 tonnes and similarly did the above three states. From the year 1968, the landings showed continuous increase till 1971. The year 1972 has witnessed a heavy decline of over 95,000 tonnes from the previous year. In fact the landings of 1972 were only slightly over 50% of the landings of 1971. The years 1973 and 1974 recorded further declines as compared to the previous years.

Seasonal aspects of mackerel fishery:

The average quarter-wise landings of mackerel(tonnes) for the states of Kerala and Karnataka are as follows:-

| | Kerala | Karnataka |
|---|---|---|
| First Quarter (January-March) | 9895 (32.7%) | 7107(26.5%) |
| Second Quarter (April-June) | 6509 (21.5%) | 1663 (6.2%) |
| Third Quarter (July-September) | 4322 (14.3%) | 993 (3.7%) |
| Fourth Quarter (October-December) | 9566 (31.6%) | 17029 (63.6%) |

The fourth quarter landings are higher than the other quarters in Karnataka. As in the case of oil sardine, second and third quarters generally recorded low landings of this fish. The first quarter has recorded substantial landings of this fish in certain years. Table-22 gives the quarter-wise landings for 1968-1978 for the two states.

Whitebait (anchovy):

Fishing/Acoustic surveys have shown that besides mackerel and oil sardine, white bait, is one of the important varieties of fish in the area under study. Mackerel and oil sardine are landed outside the area in the states of Tamil Nadu and Maharashtra in small

**Table 22**

**Ma ckerel: Quarterwise landings in Kerala and Karnataka 1968-'78**

(Figures in Tonnes)

| Year | Kerala | | | | Karnataka | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| 1968 | 503 | 14 | 248 | 2,834 | 143 | - | 96 | 5,497 |
| 1969 | 333 | 162 | 11,244 | 17,942 | 190 | 1 | 240 | 12,822 |
| 1970 | 8,784 | 8,396 | 9,796 | 30,683 | 6,821 | 306 | 1,273 | 37,937 |
| 1971 | 53,501 | 29,967 | 722 | 10,904 | 20,119 | 5,469 | 781 | 37,678 |
| 1972 | 16,727 | 8,602 | 5,015 | 4,172 | 25,631 | 1,624 | 1,546 | 3,448 |
| 1973 | 2,546 | 3,539 | 6,657 | 7,038 | 3,271 | 2,887 | 289 | 29,021 |
| 1974 | 2,285 | 319 | 2,368 | 5,363 | 4,415 | 896 | 1,130 | 1,255 |
| 1975 | 5,642 | 7,731 | 200 | 1,357 | 1,974 | 147 | 258 | 10,090 |
| 1976 | 5,760 | 16,773 | 3,434 | 6,011 | 6,001 | 4,029 | 1,089 | 11,326 |
| 1977 | 2,865 | 4,283 | 3,534 | 9,286 | 497 | 1,271 | 3,229 | 21,217 |
| 1978 | 7,412 | 2,855 | . | - | 5,358 | 650 | - | - |

*Source: Central Marine Fisheries Research Institute, Cochin.

quantities. The landing figures of these fishes (Mackerel and Oil Sardine) for the area are obtained by totalling up the complete landings of all the five constituent states viz. Tamil Nadu, Kerala, Karnataka, Goa and Maharashtra. White-bait, is landed all along the coastline more or less in a uniform pattern. Three species of the genus _Anchoviella_ viz. _A.heteroloba_, _A.bataviensis_ and _A.zollingeri_ are the main component species of white-bait stock in the area, named in the order of their abundance. The landing figures are obtained by addition of landings in the states of Kerala, Karnataka and Goa and proportionate figures for Tamil Nadu and Maharashtra i.e., one fifth of Tamil Nadu and one third of Maharashtra, landings according to the length of the coastline of those two states included in the area under study.

White-bait landings were maximum in the area in the year 1974 (21,794 t) and the all-India landings were also maximum the same year (41,507 t). The contribution from the area for the all-India landings was maximum from this fishery in the year 1972 (63%).

## Seasonal aspects of whitebait fishery:

Table-No.23 gives the quarter-wise landings of whitebait in the area. The average landings (tonnes) for each quarter for the period are as follows:

Table: 23

## Quarterwise landings of white-bait (in tonnes) within the area under study (1968-'77)

| Year | Quarter 1 | 2 | 3 | 4 | Total |
|---|---|---|---|---|---|
| 1968 | 1192 | 1722 | 1293 | 2843 | 7050 |
| 1969 | 2231 | 1001 | 3584 | 6361 | 13177 |
| 1970 | 1637 | 509 | 1389 | 6296 | 9831 |
| 1971 | 1229 | 509 | 4291 | 6333 | 12362 |
| 1972 | 511 | 1263 | 1601 | 8489 | 11864 |
| 1973 | 1096 | 1058 | 7105 | 2074 | 11333 |
| 1974 | 1002 | 4583 | 5985 | 10184 | 21754 |
| 1975 | 1012 | 5164 | 2147 | 5502 | 13825 |
| 1976 | 1383 | 2622 | 1886 | 5794 | 11685 |
| 1977 | 791 | 2484 | 6100 | 3680 | 13055 |
| Average | 1208 | 2092 | 3538 | 5756 | 12594 |

*From the data provided by the Central Marine Fisheries Research Institute, Cochin.

| | Average landings |
|---|---|
| First Quarter (January-March) | 1208 (9.59%) |
| Second Quarter (April-June) | 2092 (16.61%) |
| Third Quarter (July-September) | 3538 (28.09%) |
| Fourth Quarter (October-December) | 5756 (45.71%) |

From theabove table it is clear that the third and fourth quarters of the year comprising of the period July to December is the most important part of the year for this fishery. On an average nearly three fourths of the total landings of the year come during this period from the area under study. The states of Tamil Nadu and Kerala, forming part of the area under observation have shown this aspect significantly for most of the years during this period.

Surface fish concentrations:

The results of fishing/acoustic surveys carried out onboard "R.V. Rastrelliger" and "R.V. Sardinella" revealed the seasonal and spatial distribution of oilsardine, mackerel and white-bait fishery and also their life history and habitat (phase I progress Reports No. 2,4,6,8,9,11,12,13 and 18 of Pelagic Fishery Project, Cochin.)

The observed distribution and area of maximum abundance of oil sardine, mackerel and white bait are given in Table 24 and 25.

Oil Sardine:

The seasonal changes in the spatial distribution of adult oil sardine schools seem to follow a pretty regular pattern. During the south-west monsoon, the bulk of the adult population breeds on the middle shelf off the south-west coast, possibly in disbursed formation since positively identified schools of this species were very rarely (July, 1976) reported during June/July period. Towards the end of August, and particularly in September large sized schools were observed in the surveyed area. During October, particularly in November-December, the fish move close inshore so that very few schools are found beyond 20m. depth. This situation remains unchanged until March/April when the fish disappear from the inshore waters too. Except in the south, where young fish were found also in February, most ofthe young oil sardines are found in July-August period.

Oil sardine spawn all the year around but mainly during south-west monsoon. The principal spawning ground was found to be off the west coast between 8° 30'N and 10° 30'N, 20 miles offshore. The maturity is reached towards the end of first year of life when the fish

Table 24

Distribution of Oil sardine and mackerel in space and time within the area under observation: (between Ratnagiri and Tuticorin)

| Year | Period | Distribution of oil sardine/ mackerel | Area of maximum abundance |
|---|---|---|---|
| 1 | 2 | 3 | 4 |
| 1973 | Sept. | Between Karwar and Alleppey | Kasaragod to Cochin |
| | Oct. | Between Vengurla & Quilon | Kasaragod to Cochin |
| | Oct.Nov. | Between Ratnagiri & Tuticorin | Kasaragod to Cochin |
| | Dec. | Between Vengurla & Cape comerin | Kasaragod to Cape Comorin |
| 1974 | Jan.Feb. | Between Ratnagiri & Tuticorin | Kasaragod to Cochin |
| | Mar.Apr. | Between Ratnagiri & Trivandrum | " |
| | Apr.May. | Between Ratnagiri & Cochin | " |
| | Jun.July | Between Karwar & Cochin (Small schools recorded north and south of Kasaragod and north of Cochin near the coast off Karwar small schools were observed away from the coast.) | " |

(Contd. next page)

Table 24 (Contd.)

| 1 | 2 | 3 | 4 |
|---|---|---|---|
| | Aug. | Between Karwar & Quilon | Kasaragod |
| | Sept.Oct. | Between Bhatkal & Quilon | Mangalore |
| | Nov. | Between Karwar & Cochin | Karwar to Cochin |
| | Dec. | Between Ratnagiri & Cape comorin (few schools) | Off Goa and south of Kasaragod |
| 1975 | Feb.Mar. | Between Ratnagiri & Tuticorin (No Schools between Kasaragod and Cochin) | Off Tuticorin, Cape & South of Quilon |
| | Apr.May | Between Vengurla & Tuticorin (No Schools off Kasaragod and Cochin) | Off Calicut, Alleppey and Cape comorin |
| | May Jun. | Between Kasaragod & Tuticorin (No Schools between Alleppey and Cape comorin) | Cape Comorin to Tuticorin, Cochin to Kasaragod. |
| | Jul.Aug. | Between Mangalore & Tuticorin | Cape Comorin to Tuticorin, Cochin to Kasaragod. |
| | Sept.Oct. | Between Ratnagiri & Trivandrum | Off Alleppey, Cochin, South of Kasaragod, Coondapur, Malpe, Karwar and Vengurla. |

(Contd. next page).

Table 24 (Contd.)

| 1 | 2 | 3 | 4 |
|---|---|---|---|
| 1977 | July | Between Kasaragod & Cape Comorin (Small Schools located in the offshore waters - no schools were observed in the nearshore waters especially in areas of upwelling activity). | Between Kasaragod and Calicut in the offshore waters. |
| | Nov.Dec. | Between Kasaragod & Cochin | Off Kasaragod and Mt. Delly (large number of surface schools of mackerel observed within the surface 50 m.) |
| 1978 | Jun.Jul. | Surface fish schools were practically non-existent. | |
| 1978 | Sep.Oct. | Between Mangalore- Ratnagiri (oil sardine) at depths of 20-50m. Off Cochin and between Calicut and South of Karwar (Mackerel) | Large concentration of oil sardine Off Calicut in the inshore waters. large concentrations of mackerel off Bhatkal ($14^{\circ}$ 00 'N. lat.) in the inshore waters shallower than 20m. |

Table 25

**Distribution of Anchoviella (white-bait) in space and time within the Area under observation (between Ratnagiri and Tuticorin)**

| Year | Period | Distribution of White-bait | Area of maximum abundance |
|---|---|---|---|
| 1 | 2 | 3 | 4 |
| 1973 | Jan.Mar. | Between Ratnagiri and Quilon | Between Vengurla and Quilon |
| | May Jun. | Between Vengurla and Quilon | Between Vengurla and Quilon |
| | Jun.Jul. | Between Mangalore and Tuticorin | Between Cape comorin and Tuticorin |
| | Jul.Aug. | Between Cape comorin and Tuticorin | Between Cape comorin and Tuticorin |
| | Oct.Nov. | Between Ratnagiri and Tuticorin | Between Cape comorin and Tuticorin |
| 1974 | Mar.Apr. | Between Ratnagiri and Quilon | Between Calicut and Quilon |
| | Apr.Ma y | Between Ratnagiri and Quilon | Between Kasaragod and Cochin |
| | Jun.Jul | Between Kasaragod and Quilon | Off Cochin |
| | Aug. | Between Cape comorin and Tuticorin | Between Cape Comorin and Tuticorin |

(Contd. . . .next page)

Table-25 (Contd.)

| 1 | 2 | 3 | 4 |
|---|---|---|---|
| | Sept.Oct. | Between Cape comorin and Tuticorin | Between Cape Comorin and Tuticorin |
| | Nov. | Between Cochin and Tuticorin | Between Cochin and Quilon |
| | Dec. | Between Kasaragod and Quilon | Off Calicut |
| 1975 | Feb.Mar. | Between Ratnagiri and Quilon | Nil |
| | Apr.- May | Between Ratnagiri and Tuticorin | Between Quilon and Tuticorin |
| | May-Jun. | Between Ratnagiri and Tuticorin | Between Quilon and Tuticorin |
| | Aug.Sept. | Between Cape comorin and Tuticorin | Between Cape Comorin and Tuticorin |
| 1976 | Jan.Feb. | Between Ratnagiri and Quilon | Off Karwar |
| 1977 | July | Between Quilon and Tuticorin | Between Quilon and Tuticorin |
| | Nov.Dec. | Between Karwar and Kasaragod | Off Honawar. |
| 1978 | Jun.Jul. | Between Cape Comorin and Tuticorin | Gulf of Mannar. |

is 16 cm long. Large adult fish (150-190 mm) were caught in August and occassionally in January/March period (Phase I- Progress Report No.6). It was believed that a very high post spawning mortality eliminates older fish from the fishery so that the exploitation is carried out mainly on zero age group population (Phase I-Progress Report No.18). It seems, however, that this is valid only for the indigenous fishery, using beach seines and boat seines in very shallow waters.

Comparing the acoustic survey results with the exploratory fishing results, one can conclude that there is no firm indication that either the main fishing season (September-April) or principal fishing area (inshore waters shallower than 30m) can be extended for commercial exploitation.

Mackerel:

Similar to oil sardine, the formation of mackerel schools starts towards the end of south-west monsoon when the fish concentrate at the surface in the area of peak plankton production. From August to October many schools were observed in the surveyed area, 5-20n. miles offshore although in some years, e.g., in 1972 they were found inshore ~~ore although in some years, e.g., in 1972 they were found inshore,~~ 1-5n.miles from the coast, during the same period (Phase I-Progress Report No.2). From November to March the fish is in shallow waters and hardly any school was observed beyond 20m. depth contour. In April the offshore migration starts again, the fishing season is over and in April/May period the schools were spotted again during the acoustic surveys. Except in 1976, no mackerel schools were positively identified during the main monsoon period.

The spawning period of this fish seems to be rather extended, from April to October, and it occurs at the end of the first year of life when the fish measures 22-23 cm (Phase I-Progress Report No.18). The main spawning area is believed to be between 8$^{o}$ and 15$^{o}$N in a 10n.mile wide belt, mostly between 35 and 100 m depth. Similar to sardine, it is believed that the natural mortality is very high after the first spawning since mackerel, larger than 25cm, are very rarely caught in both commercial catches as well as in exploratory catches outside traditional fishing grounds.

Although the identification of schools was not always reliable, data based on results of exploratory fishing was available. Mackerel was found in deeper waters than sardines( June/July 1976, September 1977) and that only juveniles move inshore while the adults remain offshore (Phase. I-Progress Report No.18), where theycan be detected by Sonar. If this is a regular phenomenon, then the fishing area can be extended offshore, by using appropriate fishing vessels, e.g., small sized purse seiners or motor towing boats.

Whitebait:

Of all the fish studied during both phases of the Project, whitebait showed the clearest and steadiest pattern of the seasonal, spatial and diurnal vertical distribution. The migration pattern was repeated in all survey years, practically without exception. Between November and April the fish is more or less scattered and spread all along the area between 10 and 50 depth. In April, the southward movement starts and during monsoon period the entire stock seem to be concentrated in the Gulf of Mannar, east and south-east of Cape-comorin. During September/October the fish start again the northward migration and scatter along the coast.

It is believed that the monsoon upwelling, with cold and oxygen deficient waters close to the surface, is the main factor which causes the southward migration into more stable oceanic environment of the Gulf of Mannar. The spreading of the whitebait stock from the Gulf of Mannar coincides with the development of homogeneous well aerated water above the south-west shelf. Whitebait is found during the day close to the bottom in irregular schools and it scatter at night in dense layers, which sometimes in the Gulf of Mannar, cover the entire water column from surface to bottom.

Three species of the genus <u>Achoviella</u>, namely <u>A.heteroloba</u>, <u>A.bataviensis</u> and <u>A.zollingeri</u> are the main component species of the whitebait stocks in the area, named in the order of their abundance. Of these, <u>A.bataviensis</u> is found mostly inshore in waters less than 20m depth. <u>A.heteroloba</u> is found in the intermediate depth (15-45m) and A.zollingeri is mostly offshore, deeper than 45m (Phase I-Progress

Report No.6). The latter species is also found more abundantly in the northern region and it is possible that it migrates outside the area under observation (Progress Report No.18).

There seems to be a protracted spawning season for white bait, two peak spawnings in the pre-monsoon and post-monsoon period (Progress Report No.13,18). 50% maturity is reached at the end of first year of life when the fish measure 66 mm (A.heteroloba) and 70 mm (A.bataviensis) Life span seems to be 2 years (Progress Report No.6).

The biomass estimates showed rather wide seasonal variations. With the exception of 1975 when the maximum biomass was estimated during April/May survey and when most of the fish was in the northern region, the usual peak estimates were obtained during main concentration period in the Gulf of Mannar, from June to August. The year 1975 was also the year of maximum biomass estimates for all species and the average whitebait standing stock was estimated over 0.9 million tonnes, with a maximum estimate of 1.5 million t in April/May (Progress Report No.13).

The average biomass for all surveyed years was 457,000 tonnes but if the exceptional 1975 figure is excluded, this value would be 275,000 tonnes.

Potential catch of white bait was estimated to be 150,000 tonnes. It is very probable that this figure is on the conservative side and that even higher optimum yield could be obtained. With the present annual catch of less than 15000 tonnes the production can be increased several times. The problem is, however, that the exploitable concentrations of this fish exist only during a short period of 3-4 months (June-August/September) and that the weather is rather unfavourable during that particular period for the existing fishing craft in the main concentration area. The exploitation problem can be overcome by the use of larger vessels which can operate pelagic trawls or purseseines during monsoon.

## 4. POSSIBLE CORRELATIONS BETWEEN OILSARDINE, MACKEREL AND WHITE BAIT FISHERY AND THE OBSERVED OCEANOGRAPHIC/ BIOLOGICAL PARAMETERS :

Oil Sardine and mackerel constitute two of the major pelagic fishes in the area under study. The oil sardine fishery commences just after the beginning of the south-west monsoon rainfall and lasts from August to March, September-December being the peak period of occurrence (Jhingran, 1975). Shoals appear first in the south and then show up gradually in succession towards the north. The beginning of the fishery is marked by the entry of big-sized fish in the advanced stage of maturity. The major fishery is constituted by the medium-sized fish and the peak season generally extends from September to January. The fishery comes to an end by April/May.

Along the south-west coast of India, the mackerel fishery starts earlier in the south (South of Calicut) by August and lasts up to February. The area between Calicut and Ratnagiri is very important as far as the mackerel fishery is concerned. Between Calicut and Mangalore, the fishery starts in August/September and lasts till March/April. North of Mangalore, the fishery starts late in October/November and lasts till February/March. Both oil sardine and mackerel make large scale migrations from off shore to inshore waters and from south to north along the south-west coast, immediately following the south-west monsoon rainfall.

There were several attempts made in the past to explain the fluctuations of pelagic fishes such as mackerel and sardine around Indian waters and other regions and relate them with one or more of the Oceanographic parameters. Contributions made by Buys (1957), Carruthers et al (1959), Marr(1959), Radovich (1959), Uda (1952), Walford (1946), Hela and Laevastu (1962,1962,1970), King and Heda (1957), Silliman (1950), Panikkar (1949), Chidambaram and Menon (1945) Bhimachar and George (1952) Noble (1972) Pradhan and Reddy (1962), Murthy (1965), Banse (1959,1968), Prabhu et al (1972), Subramonyan (1973), Antony Raja (1974), Pillai and Perumal (1975), Currie et al (1971), Devanesan (1943) Dragesund (1970), George (1953), Mukundan (1971), Prasad (1969), Ramamurthy (1965), Rao (1973), Cushing (1971) Murthy and Edelman (1966), etc. are worth mentioning in this context.

Panikkar (1949) observed that delays in the onset of monsoon on the Indian Coast are often followed by delays in the fishing seasons for mackerel as well as oil sardine. Chidambaram and Menon (1945) found correlation between the landings of mackerel and the environmental factors such as rainfall, surface temperature, salinity, specific gravity of sea water and planktonic abundance in the areas of fishing . Bhimachar and George (1950) observed that the mackerel landings show their peak and coincide with or follow the abundance of plankton.

Noble (1972) reported an inverse correlation existing between sea surface temperature and duration of mackerel fishery off Karwar. During 1955-1956 and 1956-1957 the minimum sea surface temperature during the south-west monsoon period decreased with a corresponding increase in the duration of the mackerel fishery. During 1958-1959 the minimum once again dropped to the lowest value for the previous 11-year period and the mackerel fishery season was the longest. During 1961-1962 the sea surface temperature recorded during the south-west monsoon period was the highest for the previous 11-year period and the duration of the fishery was the shortest. According to Murthy (1965) the clue for the seasonal and regional variations of both sardine and mackerel fishery has to be found partly, if not wholly, in the variations of the pattern of the coastal currents. According to him catches are maximum during winter season when the northerly drift gets established along the coast. According to Rao et al (1973) the oil sardine fishery dominates between Alleppey and Malpe and mackerel fishery between Calicut and Malwan. The northern areas appear to be more favourable for mackerel fishery, probably due to a sudden increase in salinity occurring northwards from the region off Mangalore(Ramamirtham et al (1965). December appears to be the peak season for oil sardine and October for mackerel. In December sinking of the offshore waters (coastal convergence) occurs over the shelf and a well defined thermal layer of about 75-100m thickness is present along the west coast (Ramamirtham and Jayaraman, 1960). It is well known that convergence bring in concentration of zooplankton (Hela and Laevastu, 1962). It is observed that zooplankton dominates in the food of oil sardines (Noble). Hence the abundance of oil sardines may be related to the phenomenon of convergence along the coast. Mackerel normally feeds at the surface (Hardenberg, 1956). Rao and Rao (1957) have observed that juvenile mackerel is selective in its food habit and adult ones are planktonic feeders. Hence it is probable that areas where plankton productivity is high, constitute a favourable environment for mackerel. During the south-west monsoon season there is decrease in the salinity of sea water due to rainfall at the surface levels. Low salinity is favourable for phytoplankton production (Subramonyan 1959). In both oil sardine and mackerel fishery the maximum abundance is found between Mangalore and Malpe when the upwelling intensity was also maximum. The mechanised fishing operations in the area between Cannannore and Mangalore proved to be better during the post-monsoon period of the year 1962 than the south Malabar coast where upwelling was not intense during the same period (Ramamirtham 1967).

It is possible that the fish moves along with the northward current which in turn produces convergence zones where zooplankton accumulates and the migration of these fishes is related to feeding conditions.

Pradhan and Reddy (1962) have reported that high temperature affected the mackerel fishing adversely off Calicut. According to Ramamurthy (1965) the mackerel season in north Kanara Coast coincided with the transition period from the low salinity and low temperature conditions during the south-west monsoon to the high salinity and warmer conditions in summer.

Pradhan and Reddy (1962) found an inverse correlation between annual rainfall and mackerel catches off Calicut. The sardine fishery at Ullal was lowest (52.1 t) in 1963-1964 when the rainfall was heaviest (306.5 cm). The catches were better during 1965-1966 and 1966-1967 (283.7 t and 385.6 t respectively) when the annual rainfall was comparatively low. (274. 1cm and 283.6cm respectively) (Prabhu et al. 1972).

Hela and Laevastu (1962) reported that the depth of the pelagic shoals depends largely on the vertical extension of the mixed layer. Similarly the vertical distribution of the buoyantly floating eggs and larvae of pelagic fishes is dependent on the vertical extent of the surface mixed layer (King and Hida 1957, Silliman 1950).

The present study revealed the following possible correlations between some of the observed oceanographic and biological parameters and the occurrence and migration of oil sardine, mackerel and white-bait (Anchovy) within the area under study. A brief resume of observations on oceanographic conditions, plankton and fishery for oil sardine, mackerel and white-bait made onboard "R.V. Rastrelliger" and "R.V. Sardinella" during the period 1971-1978 is given in Table-26.

made onboard "R.V. RASTRELLIGER" and "R.V. SARDINELLA" during

1971 - 1978.

| Year/ Month | Area | No. of Surveys undertaken | Observations on Oceanographic conditions | Observations on plankton | Observations on oil sardine, mackerel and anchoviella fishery |
|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 |
| 1971 Aug. | COCHIN | 4 | Thermocline very shallow at coastal stations. | - | Maximum echo abundance of pelagic fish at lat. 9°46'N lat. 76°08'E long. Mackerel schools between 10-20m. |
| 1971 Sept. | COCHIN | 4 | Do | | Several Mackerel Schools. |
| | COCHIN TO KARWAR | 1 | Thin layer of surface mixed layer, low oxygenated more pronounced at the northern stations. | | Fish distributed within the top 15-20m. both oil sardine and Mackerel, in schools within 6-20 n. miles from the coast. Schools observed both during day and night -exhibited bioluminiscence at night- Numerous schools sighted north of 11° 30'N. lat. - both oil sardine and Mackerel schools present - Mackerel being dominant in the northern part - schools fast moving. |

(Contd. .next page)

Table-26 (Contd.)

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| 1971 Oct. | COCHIN TO QUILON | 1 | More or less uniform distribution of dissolved Oxygen (4ml.$O_2$/L) from 0-30m. at the coastal stations. | | Wide vertical distribution of fish noticed up to 30 m. 22 schools of oil sardine and mackerel recorded by echo sounder. 10 directly observed at night-mostly in the Quilon area. |
| 1971 Nov. | COCHIN | 2 | Do | | Several mackerel schools observed 1-2n. miles west of fairway buoy. |
| | COCHIN TO CALICUT | 1 | Do | | 8 schools of oil sardine and mackerel recorded in the area. |
| | COCHIN TO KARWAR | 1 | Do | | Mackerel schools sighted near KARWAR. Slow moving sardine schools north of Cannanore - also a big mackerel school with a horizontal extension of ½ n. mile - dense from 0-8 m. |
| 1971 Dec. | COCHIN TO TRIVANDRUM | 1 | Do | | Very few fish recording within 2-3 n. miles from the coast - the low fish density water extended seaward 20 n. miles off Quilon- Large dense schools of oil sardine observed of Alleppey. |

(Contd. . . .next page).

Table-26(Contd.)

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| | COCHIN | 2 | Do | | Small sardine schools observed between 10-15 m. |
| 1972 Jan. | COCHIN TO MALWAN | 1 | Top 100 m. homogeneous with regard to sea water temperature and dissolved oxygen. Thermocline at 100-125 m., below which the dissolved oxygen decreased. | | Surface schools of mackerel between 12° N. and 14° N. lat.-sardine schools observed in the Malpe area. |
| 1972 Feb. | COCHIN TO KASARAGOD | 1 | Top 100m. homogeneous with regard to sea water temperature and dissolved Oxygen. Thermocline at 100-125m. | | Very few schools of oil sardine and mackerel were observed. |
| | COCHIN TO VENGURLA | 1 | Do | | Several small schools of oil sardine at surface levels - Mackerel was observed only off Karwar. |
| 1972 Mar. | COCHIN TO QUILON | 1 | | | Anchoviella recorded in less than 25 m. depth. Shoreward shift of Anchoviella noticed. |
| | COCHIN TO TRIVANDRUM | 1 | | | |
| | COCHIN TO MANGALORE | 1 | | | |
| | COCHIN TO MANGALORE | 1 | | | |

(Contd. . .next page).

Table-26 (Contd.)

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| 1972 May | COCHIN | 2 | Current at sea surface southerly-approx.velocity 2 knots. | | Numerous sardine and mackerel schools near surface generally moving in a N.W. direction. Schools diue deeper at noon. Towards dark individual schools clearly merged in to longer aggregates - 'snake like ' schools were seen later at night as evidenced by bioluminiscence- Behavioural difference between mackerel and oil sardine schools observed. Mackerel actively feeding, swimming, densely packed at surface levels with mouths open. Fish in general not being easily scared - ideal conditions for purse-seining. |
| | COCHIN | 1 | | In addition to anchoviella layer close to the bottom, dark layer composed of planktonic organisms observed in the upper 15m. Lot of medusae were caught-black recordings probably caused by medusae. | Several Sardine schools disappeared from surface as suddenly as they appeared. |
| | COCHIN | 1 | | | |

(Contd. next page).

Table-26 (Contd.)

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| 1972 JUN. | COCHIN TO CALICUT | 1 | Surface waters 40 m. in thickness over cold waters with low dissolved oxygen content. There is an indication that the cold low oxygenated waters at 50 m. depth moving up towards surface near the coast. surface current southerly. | Several small surface schools of mackerel within 5.15 m. miles belt upto 10° 40'N. lat. vast areas of surface water within 15-20n.miles belt between Calicut and Ponnani covered with brown patches of Trichodesmium. | Schools of young mackerel observed 20 n. miles S.W. of Cochin along with anchoviella and catfish. |
| 1972 AUG. | COCHIN | 1 | | | Large No. of surface schools of mackerel within 2-3n. miles from the coast. |
| 1972 SEPT. | COCHIN | 1 | Winds N N W. | Red water phenomenon observed in the Coastal waters between 10-20 m. | Fish schools observed within the Red water at surface levels. |
| | COCHIN TO GOA | 1 | | | Mackerel concentration at surface levels seems to be moving northward and closer to the shore. |

(Contd. . .next page).

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| 1972 Oct. | COCHIN | 1 | Surface temperature 29.2°C to 30.2°C Thermocline between 30-35 m. | | |
| OCT. NOV. | COCHIN TO GOA | 1 | | | Numerous sardine schools off Goa 10-12 n. miles away from the coast. They are found close to the shore off Vengurla. At Monawar and Karwar they remain mostly in the bays-no schools observed in the off-shore area. |
| 1972 Dec. | COCHIN | 1 | Surface temperature 28.4°C to 29.0°C | | |
| 1973 Jan. | COCHIN | 2 | | | |
| | CALICUT TO TUTICORIN | 1 | Sharpvertical gradients in Sea water temperature off Cape-comorin. Thermocline at 75-125m. Dissolved oxygen dropped below Thermocline-outer parts of wadge bank covered with partly oxygenated water. | Plankton density in general low - increased towards the southern end of cape-section. Fish larvae very few. | Significant recordings of fish on the wadge bank between 35.58m. no fish below 75-100m (Thermocline) |
| 1973 Feb. Mar. | CALICUT TO RATNAGIRI | 1 | Thermocline at 75 m. Above this temperature and salinity increased towards north. Oxygen below thermocline decreased towards north-off Ratnagiri samples from 500 m. depth contained $H_2S$. | Plankton density in general low | Anchoviella dominant in the area, especially off Karwar where they formed large sized distinct schools. |

Table-26 (Contd.)

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| 1973 Mar. | COCHIN TO TUTICORIN | 1 | Thermocline very sharp off Quilon and Cape. Minimum $O_2$ ($0.5 ml O_2/L$) from 100-200m. | Plankton volume low | Anchoviella between 0-4m. depth from Cochin to Quilon. |
| 1973 Mar. Apr. | COCHIN TO KARWAR | 1 | | Plankton volume low | |
| 1972 Apr. | COCHIN TO TRIVANDRUM | 1 | Indications of upwelling off Quilon | Plankton volume shows slight increase off shore. | |
| 1973 May | COCHIN | 1 | Indications of upwelling off Cochin | | |
| 1973 May Jun. | CAPE TO RATNAGIRI | 1 | Upward shift of Thermocline at all sections. Density decreased towards south at surface levels. | Increase in the Standaing crop of Zoo-plankton in the Southern sections. | |
| 1973 Jun. July | MANDAPAM TO RATNAGIRI | 1 | Upward shift of Thermocline. Density at surface decreased towards South-lifting of the Oxycline towards the shore between Calicut and Cape. | Plankton volumes increased - A belt of phytoplankton observed near the shore in the southern Sections. | |

(Contd. . .next page.)

Table -26 (Contd.)

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| 1973 Nov. Dec. | MANDAPAM TO RATNAGIRI | 1 | $O_2$ minimum between 150-200m. - warm surface layer of low salinity . salinity increased to a maximum just above the Thermocline. | Plankton densities moderate. | |
| 1974 Jan. | RATNAGIRI TO TUTICORIN | 1 | Surface temperature increased towards north. Salinity comparatively low-waters well aerated at Thermocline. (125-200m.) | Plankton densities moderate highest off Cochin. | Anchoviella - low density all over between Cochin and Kasargod and between Cape and Mandapam. *Anchoviella heteroloba*, *A. bataviensis* and *A. zollingeri* north of Cochin. *A. commersoni* observed in the Gulf of Mannar. |
| 1974 Feb. Mar. | MANDAPAM TO DWARAKA | 1 | Surface temperature very low off Dwaraka-reaching to high values(34°C)off Tuticorin. Thermocline at 100m off Karwar and between 75-100m between cochin and Tuticorin. | Plankton density low | Anchoviella observed between Quilon and Ratnagiri within 5-30M. miles from coast. No Schools of adult mackerel or oil sardine observed north of 20°N. lat. |

(Contd. next page).

Table-26 (Contd.)

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| 1974 Mar. | COCHIN TO QUILON | 1 | Surface temperature relatively high. upward shift of top of thermocline. | Fish larvae in few numbers in the inshore belt. | Anchoviella noticed in the Cochin-Quilon area. |
| 1974 Apr. | COCHIN TO MANDAPAM | 1 | | | |
| 1974 Apr. | KASARAGOD TO RATNAGIRI | 1 | Thermocline below 75 m. | | Anchoviella recordings in the area from Coondapur to Ratnagiri upto 20 n. miles from shore. |
| 1974 Apr. May. | RATNAGIRI TO TUTICORIN | 1 | Surface temperature decreased between Quilon and Tuticorin-upward shift of thermocline at all sections except off Tuticorin. Upward shift of oxycline at all sections. Distribution of Temperature and $O_2$ confirmed the presence of upwelling in the area between Kasaragod and Quilon. | Plankton densities low | White - bait concentrations found within a belt between Kasaragod and Quilon. |

(Contd. next page).

Table-26 (Contd.)

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| 1974 Jun. July. | COCHIN TO KARWAR | 1 | Upward shift of Thermocline and Oxycline (20.30m.) | *Sardinella* larvae seen off Cochin, Kasaragod and Ratnagiri. Mackerel larvae seen only off Cochin. Oil sardine eggs and larvae noticed between Quilon and Karwar. | White-bait concentrations shifted to south of Cochin. |
| 1974 Aug. | RATNAGIRI TO TUTICORIN | 1 | Thermocline and Oxycline at the surface between Kasaragod and Quilon. Narrow belt of low $O_2$ observed between Karwar and Cochin and at surface levels. | plankton biomass high between Ratnagiri and Quilon. Fish eggs and larvae noticed only off Kasaragod, Quilon and Tuticorin. | White-bait recordings observed only south of Cochin - main stock distributed between Trivandrum and Mandapam in the Gulf of Mannar. The South ward migration of White-bait mentioned during June - July seems to be completed and the stock accumulated on the shelf in the Gulf of Mannar with huge concentration east of Cape-comorin(Average catch/hr. for the pelagic trawl operated in the area was429 kg.) |
| 1974 Sept. | COCHIN TO TUTICORIN | 1 | Slight downward shift of Thermocline and Oxycline in the Cochin Quilon region in contrast to their upward movement between cape and | High plankton density observed in the Quilon Tuticorin area. | White-bait observed east of Cape-comorin. The stock has moved closer to the coast predominantly *Anchoviella heteroloba*. Pelagic trawl |

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Table-26 (Contd.)

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| | | | Tuticorin. oxygen concentrations low at the surface levels off cape comorin. | | yielded 7200-45000 kg./hr. with an average catch/hr. of 26700 kg. Mackerel and oil sardi schools were observed at 5 places between Quilon and Mangalore within 5-25 m. miles from the coast. |
| 1974 Oct. Nov. | RATNAGIRI TO TUTICORIN | 1 | Characteristic features of upwelling still prevailing in the northern sections. South of Karwar-no upwelling. | General increase in plankton biomass | White-bait observed between Cochin and Manapad. The main part of white-bait stock started migrating along the coast in a N.W.direction. |
| 1974 Dec. | RATNAGIRI TO TRIVANDRUM | 1 | Northerly current at surface levels along the coast as evident from the density distribution. | | White-bait migrated upto 13° 50' N lat. within the inner and middle shelf. |
| 1975 Jan. | KASARAGOD TO KARWAR | 1 | | | Poor fish recordings in the inshore area, within 0-15m. Above 15m and upto 80 m. the recordings are better. |
| 1975 Feb. Mar. | RATNAGIRI TO TUTICORIN | 1 | Surface water well aerated-low oxygen below 150m. | Plankton biomass low. | |

(Contd. . . next page.).

Table-26 (Contd.)

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| 1975 Apr. | RATNAGIRI TO TUTICORIN | 1 | Surface temperature increased towards south up to cochin. Thermocline at 75m. between Ratnagiri and Kasaragod. It was at 30m off Cochin and cape. low oxygenated water below 180 m in the north and 125 m in the south. | Plankton density low. Fish larvae comparatively high except off Kasaragod. | White-bait observed up to 50 m. depth. |
| 1975 May | COCHIN TO CAPE | 1 | | | Schools of oil sardine observed 5.n. miles south of Trivandrum. |
| 1975 May Jun. | RATNAGIRI TO TUTICORIN | 1 | Surface temperature decreased towards south. Upward shift of Thermocline and Oxycline - southerly current at surface levels. presence of upwelling. | | Plankton biomass low between Ratnagiri and Kasaragod - south of Kasaragod it increase - fish eggs and larvae density high except off Ratnagiri. |
| 1975 July | KASARAGOD TO MANAPAD | 1 | | Plankton biomass showed an increase. Mackerel fry between 30-40m off Kasaragod. Oil sardine fry between Calicut and Alleppey, together with young Sardines in the area west of cape and the eastern slope and the wadge bank. | |

(Contd. next page).

Table-26 (Contd.)

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| 1975 July Aug. | RATNIGIRI TO TUTICORIN | 1 | Upward tilt of Thermocline and Oxycline-process of upwelling active in the area between Kasaragod and Quilon. Mid-shelf Covered with low oxygenated cold water. | Larvae of Sardine & white-bait observed between Quilon and Karwar. | White-bait continued its concentration in the Gulf of Mannar, close to the coast north of Karwar, destributed in the inner and mid-shelf with in 30-35 m. between Cochin and Tuticorin. Catch/hr: 1000-1100kg. using mid water trawl. |
| 1975 Aug. Sept. | COCHIN TO GULF OF MANNAR | 1 | Monsoon conditions - surface current southerly, most of the shelf covered with low oxygenated water. | Plankton density increased between Cochin and Quilon. | White-bait moved closer to the shore - dense concentrations were observed in the gulf of Mannar area in shallow waters between 15-20 m depth - Average catch/hr: 1800 kg. using mid water trawl. |
| 1976 Jan. | RATNAGIRI TO TUTICORIN | 1 | Thermocline between 75-100m except off Kasaragod (100-125m) surface temperature maximum at Cochin. Surface waters well aerated up to the level of Thermocline. | Plankton bio-mass low-fish eggs and larvae moderate. | |

(Contd. . .next page).

Table-26 (Contd.)

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| 1976 Jun. July | RATNAGIRI TO TUTICORIN | 1 | Horizontal gradients indicated southerly flow south of Cochin. Low salinity at northern coastal stations probably due to rainfall phenomenon of upwelling more pronounced south of Cochin. | | Densest concentrations of breeding oil sardine located off mt. Delly where the temperature gradient was less (between 26-27°C) Most of the pelagic fish schools observed in less than 50 m depth. densest concentration between Calicut and Kasaragod within 10-25 m, mainly breeding oil sardines. |
| 1976 Oct. | RATNAGIRI TO CAPE | 1 | | | Most of the oil sardine and mackerel Schools migrated to inshore areas. |
| 1977 July | RATNAGIRI TO CAPE | 1 | Evidence of strong upwelling in areas off and South of Calicut-Comparison of temperature values at sea surface for the period 1974-77 indicated unusually low temperature at stations located south of Kasaragod which is indicative at stronger upwelling. | Plankton biomass high between cape and Cochin, Kasaragod to south of Karwar, and also vengurla to Ratnagiri. Plankton biomass increased offshore. | Bulk of the pelagic fish population, especially oil sardine and markerel were found to avoid the upwelling area with low temperature and low dissolved Oxygen. Relatively less spawning activity in the inshore area. The spawning of oil sardine and mackerel has not been dense. |
| 1977 Sept. | MANGALORE TO TO RATNAGIRI | 1 | Thermocline at the surface levels in the inshore stations-entire shelf occupied by high saline waters - week flow at the surface levels in a southerly direction-except for the first few metres, entire shelf occupied by low $O_2$ waters. | Plankton biomass low | Concentrations of surface schools of oil sardine and Mackerel very near the shore at Goa (20m), Malpe(12m), Good catches of oil sardine obtained at night when there is no moon light. |

Table 26-(Contd.)

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| 1977 Nov. Dec. | CAPE to RATNAGIRI | 1 | Surface temperature decreased towards north - positive inversions between 0-30m. Theremocline below 30-50m. Effect of upwelling noticed below 20m off Ratnagiri. Surface waters well mixed upto 50m. weak, less developed northerly flow at the surface levels. | Low plankton biomass off Tuticorin and Cape. Highest off Ratnagiri. | 90% of Pelagic schooling fish occured between 10-60m. mackerel (833kg/hr.) caught S.W. of Cochin at 22m. depth along with oil sardine. |
| 1978 Jun. July | RATNAGIRI TO TUTICORIN | 1 | Thermocline starts at the surface off Cape, Kasaragod, Quilon (coastal stations) Towards north theremocline starts at deeper levels (10-20m). evidence of upwelling off Quilon. | Plankton biomass high off Tuticorin, Cochin and Karwar. | Dense concentration of White-bait in the gulf of Mannar, 15n. miles S.E. of cape within 35-49m. During day they occur close to the bottom in dense irregular shoals, 5.30m in height. At dusk, the shoals start moving closer to the surface and they slowly disintegrate so that by nightfall they form a dense scattering layer. Subsequent fishing trips showed that 5 Tons/hr. of white-bait can be easily caught in the above area using a pelagic trawl. |

(Contd. next page)

Table-26 (Contd.)

| 1 | 2 | 3 | 4 / 5 | 6 |
|---|---|---|---|---|
| 1978 Jul. Aug. | KARWAR TO CAPE | 1 | Comparison of surface temperature values for July-August for the period 1974-78 indicated low temperature off cape, Quilon, Calicut and Kasaragod. Also comparatively low $O_2$ values at surface levels at all coastal stations except off Calicut. High density waters at coastal stations off cape, Quilon, Calicut and Kasaragod. Thermocline starts at the surface except off cape. Evidence of strong upwelling of bottom waters to the surface off Kasaragod. | Zoo plankton increased double fold when compared to that in 1977. Swarms of Doliolum noticed between Calicut & Kasaragad, and Phytoplankton abundance significant in the Kasaragod and Karwar sections. Average number of spawn products high in the area between Kasaragod and Alleppey. Most of the mackerel larvae occured between Kasargod and Alleppey the highest activity being at Kasaragod. | |
| 1978 Sept. Oct. | TUTICORIN TO RATNAGIRI | 1 | It was observed that the process of upwelling has a northward limit up to Karwar. observations made off Ratnagiri indicated highly stable conditions | Zooplankton biomass high off Cochin at the Coastal stations and low at the offshore stations. | Oil sardine schools observed between Mangalore and Ratnagiri. Largest concentration off Calicut in the inshore waters. Mackerel schools off cochin and between Calicut and south of Karwar. Large concentrations of mackerel off Bhatka in the inshore waters within 20m depth zone. |

Oil Sardine and mackerel:

The process of upwelling commences earlier in the south and slowly extends towards north. The low dissolvedooxygen concentrations of the upwelled water compel the fishes to avoid, temporarily, areas of intense upwelling. Hence their vertical distribution during this season is limited to a narrow column above the top of the thermocline. When the comparatively cold waters of the thermocline with the associated oxygen minimum layer rises along the continental shelf, it is observed that part of the fish population moves in front of it in to shallow surf mixed waters and part moves offshore away from the centre of strong upwelling. The plankton bloom following the upwelling attracts these plankton feeders to move behind the northward spreading of the upwelling to take advantage of the plankton bloom.

As upwelling spreads northwards, the sea surface temperature falls to the optimum levels of tolerance for these fishes, thus providing them with the favourable conditions at the surface levels.

During the peak of south-west monsoon rainfall, the sea surface salinity falls substantially all along the coast due to rain and river runoff. The influence of the southward spreading of the high salinity Arabian sea water during this season is nullified by the rainfall and river runoff. But the situation is reversed with the northward spreading of upwelling. They move along with the northward spreading of the upwelling conditions which provide them with the optimum salinity conditions. The northward migration of these fishes is confined to the northern limit of the region of upwelling. However it is observed that except for the juveniles, salinity is not a major limiting factor when compared to temperature and dissolved oxygen.

During the pre-monsoon (south-west) period (March-April) the sea surface temperature increases and the continental shelf is occupied by comparatively high temperature and high salinity waters. To avoid these unfavourable conditions, both oil sardine and mackerel migrate away from the coast into deeper water during March-April. A comparison of the monthly mean temperature (10m. depth at 2nd station from the coast) for the period July-October for the upwelling area between Quilon and Karwar indicated a mean temperature range of 23.4 to 26.4°c. In theRatnagiri section the same varied between 27.5°c and 28.3°c during the same period. From these contrasts in the spatal variations of sea water temperature and the northern limit of the fishery for oil sardine and mackerel, it could be inferred that these fishes have less tolerence for temperature above 27.0°c. After March when the sea surface temperature increased much above the limit of tolerence, (27.0°c) the fishery gradually subsided and by April-May these fishes moved away from the coast to deeper waters of comparatively favourable conditions.

Due to the spatial and year to year variations in the onset, intensity and duration of the monsoon and the associated upwelling, the fishery for oil sardine and mackerel exhibits similar fluctuations in space and time (Table-24).

During 1976 (June-July) some of the densest concentrations of breeding oil sardines were located off Mt. Delli where the temperature gradients were comparatively less ($26^{o}$-$27^{o}$c). Concentration of breeding oil sardines were also found between Calicut and Kasaragod, within 10-15m. miles from the coast in less than 50m. depth. Perhaps it would mean that oil sardine prefer areas with comparatively less vertical temperature gradients for breeding purposes and normally they move away from the coast in search of suitable environment, once they attain the required maturity.

During July 1977, it was found that bulk of the pelagic fish populations avoided areas ofupwelling intensity with low oxygen concentrations. Relatively less spawning activity was noted in the coastal waters during this season. The survey conducted between Mangalore and Ratnagiri in September (1977) showed that except for the first few metres of the water column, the entire shelf was occupied by low oxygen water. It was noted that even demersal fishes, with rare exceptions, were absent in areas with oxygen concentrations less than 2ml/l. The survey during July-August 1978 indicated that the average number of spawn products was high between Alleppey and Kasaragod. Intense fish spawning activity, with the peak off Kasaragod, was noted in this area. The sea surface temperature in this area was comparatively low (22.61 to $26.32^{o}$c) with comparatively less vertical gradients. Oxygen concentrations, which were comparatively low below 20m, slowly increased towards offshore waters (0.16-2.76 ml $O_2$/L).

Compared to mackerel, oil sardine was found to have lesser tolerance for high salinity waters. This aspect is clearly evident from the restricted northward migration of the latter up to Karwar.

White-bait:

The white-bait in the area under study exhibited large scale seasonal migrations. The observed seasonal fluctuations in distribution, in space and time, along with areas of maximum abundance is given in Table-25.

From the table, it is evident that white-bait is distributed on the shelf between Ratnagiri and Quilon during May. But during the south-west monsoon period, between June and September, they migrate southwards and later south-eastwards to the Cape-comorin-Tuticorin area. The southward migration seems to be closely related to be southerly flow at the surface levels which takes effect during the monsoon.

It is possible that white-bait makes the southerly migration during June-July mainly to avoid the comparatively high temperature (above 28°c) prevailing in the Ratnagiri-Karwar region. When they reach further south, the effect of the low temperature and less aerated (less than 23°c and 2 ml/O2/L) upwelled water for which also the fish has less tolerence, drives it further south and later towards south-east where comparatively favourable temperature (between 24°c) and 27°c) and dissolved oxygen conditions (2ml $O_2$/L and above) prevail. During the period June-October, the fish remains in the area between Cape-comorin and Tuticorin in dense concentrations extending from the surface to the bottom exhibiting the typical diurnal vertical migrations. Jhingran (1975) observed that the spawning of Indian anchovy takes place during November-March. The present study indicated that the northward migration of the fish starts by early November. The setting up of the northerly current with the post monsoon conditions prevailing along the south-west coast viz. comparatively higher oxygen concentrations, the plankton bloom which followed the upwelling and the gradual rise in temperature resulting from the recession of the upwelling process provide the fish with the favourable environmental conditions. By December the distribution spreads almost all along the area. During both southward and northward migrations exhibited by the fish the prevailing surface currents also favour the passive floating and drifting.

## 5. POSSIBILITIES OF FORECASTING THE OIL SARDINE, MACKEREL AND WHITE-BAIT FISHERY IN THE AREA UNDER STUDY

The major pelagic fisheries of the south-west coast of India, mainly those for oil sardine and mackerel show large scale fluctuations in their occurrence, distribution and abundance. More or less same is the case with the anchoviella (white-bait) fishery which exhibits large scale migrations. The above mentioned fluctuations assume great significance especially because of their impact on the total marine fish catches of the country. The average annual catch (1973 -

1977) indicate 1,45,000 tonnes of oil sardine, 57,000 tonnes of mackerel and 32,000 tonnes of whitebait. As regards oil sardine almost 99% of the catches are landed along the Kerala and Karnataka coasts. The fishery starts some time in August and continues upto April-May with the peak during October-January. The average potential standing stock of oil sardine has been estimated to be about 400, 000 tonnes of which at least 50% could be harvested. The mackerel fishery is mainly concentrated along the coasts of Goa, Karnataka and Kerala during the period August to April-May. The estimated average standing stock is about 300,000 tonnes. The white-bait fishery, which exhibits large scale seasonal migrations, is mainly distributed between Lat. $14^{\circ}$N and $8^{\circ}$N Lat. from October to May and thereafter in the area between Cape-comorin and Tuticorin during June-August. The standing stock of white-bait has been estimated to be around 400,000 tonnes.

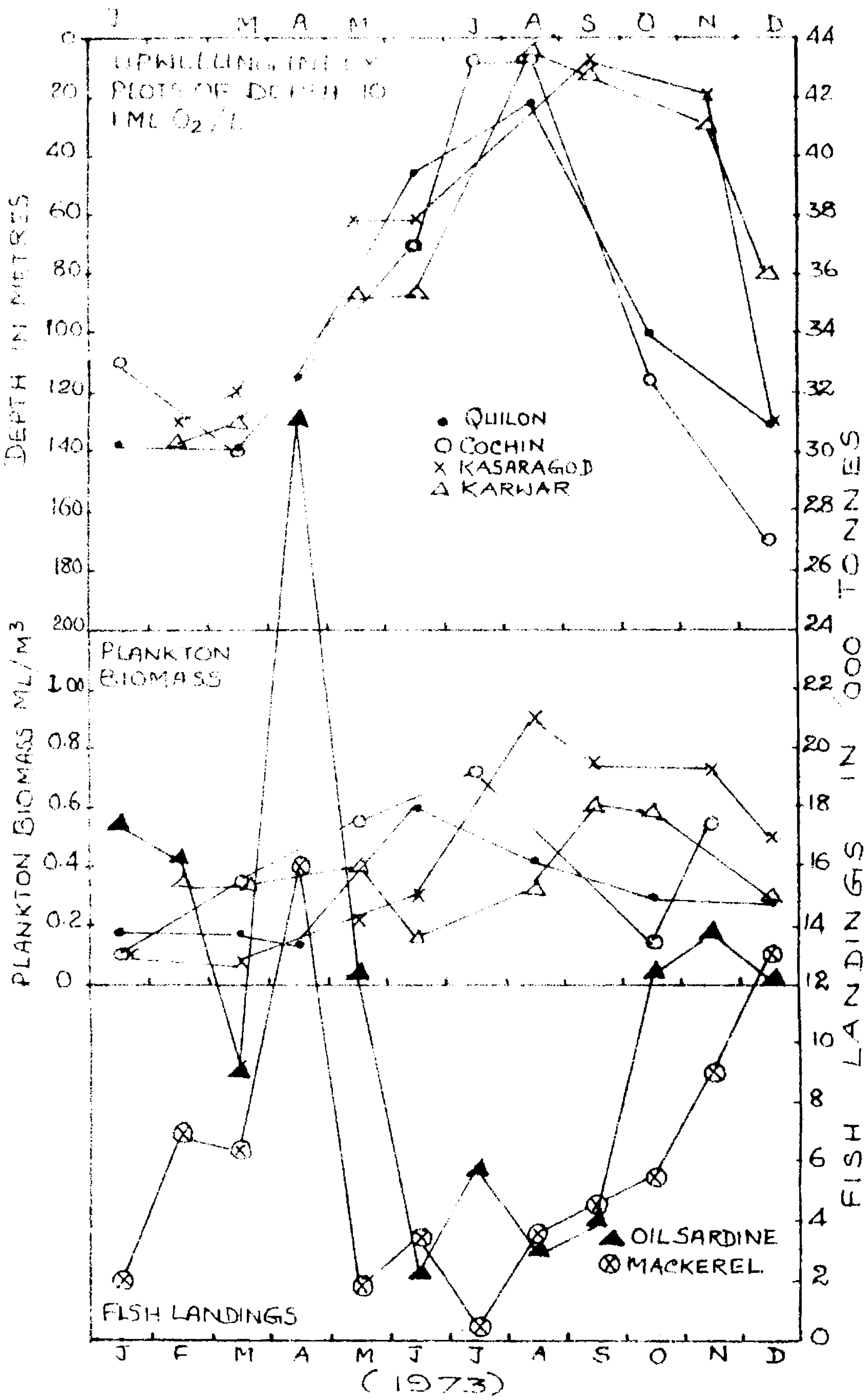
Taking into consideration the existing facilities available in the country for a rational exploitation of the above major pelagic fishery resources and also the various limiting factors, such as the number and location of operating bases, the cruising range of different types of fishing crafts, the weather conditions, availability of suitable fishing gear, storage/processing facilities both onboard and ashore, infrastructure for loading of fuel, ice and water, unloading of catches and marketing facilities; reduction of searching time to the bearest minimum assumes great significance. This is especially the case with the non-mechanised and small mechanised crafts, whose operating ranges are comparatively smaller. The above objective could be achieved by means of timely forecasts, within reasonable limits, with regard to the availability of fishable concentrations of some of the above fishes by monitoring some of the relevant oceanographic and biological parameters which are known to influence the movement of these fishes either directly or indirectly.

The Oilsardine, mackerel and anchoviella fisheriesof the area under study are directly influenced by the prevailing ocean currents, seasonal changes in seawater temperature, salinity and dissolved oxygen, phenomenon of upwelling and the resultant sequences of primary and secondary production. This direct relationship is depicted in fig. 16 and 17 illustrating the relationship between upwelling, plankton biomass and the landings of oil sardine and mackerel. The possible time gap between the upwelling peaky plankton bloom and the availability of fishable concentrations of oil sardine/mackerel/white bait, to a certain extent depends upon the intensity of the triggering phenomenon (upwelling) and also the relative intensity of the various opposing forces such as deoxygenation, fresh water runoff, unfavourable surface winds etc.

It is possible to evolve a prediction system by monitoring the relevant oceanographic and biological parameters in the area and forceasting, within reasonable limits, the availability of fishable concentrations of the above mentioned fishes in space and time. Similar forecasts will assist the fishermen in better planning of fishing operations and to minimise the searching time, thereby reducing the

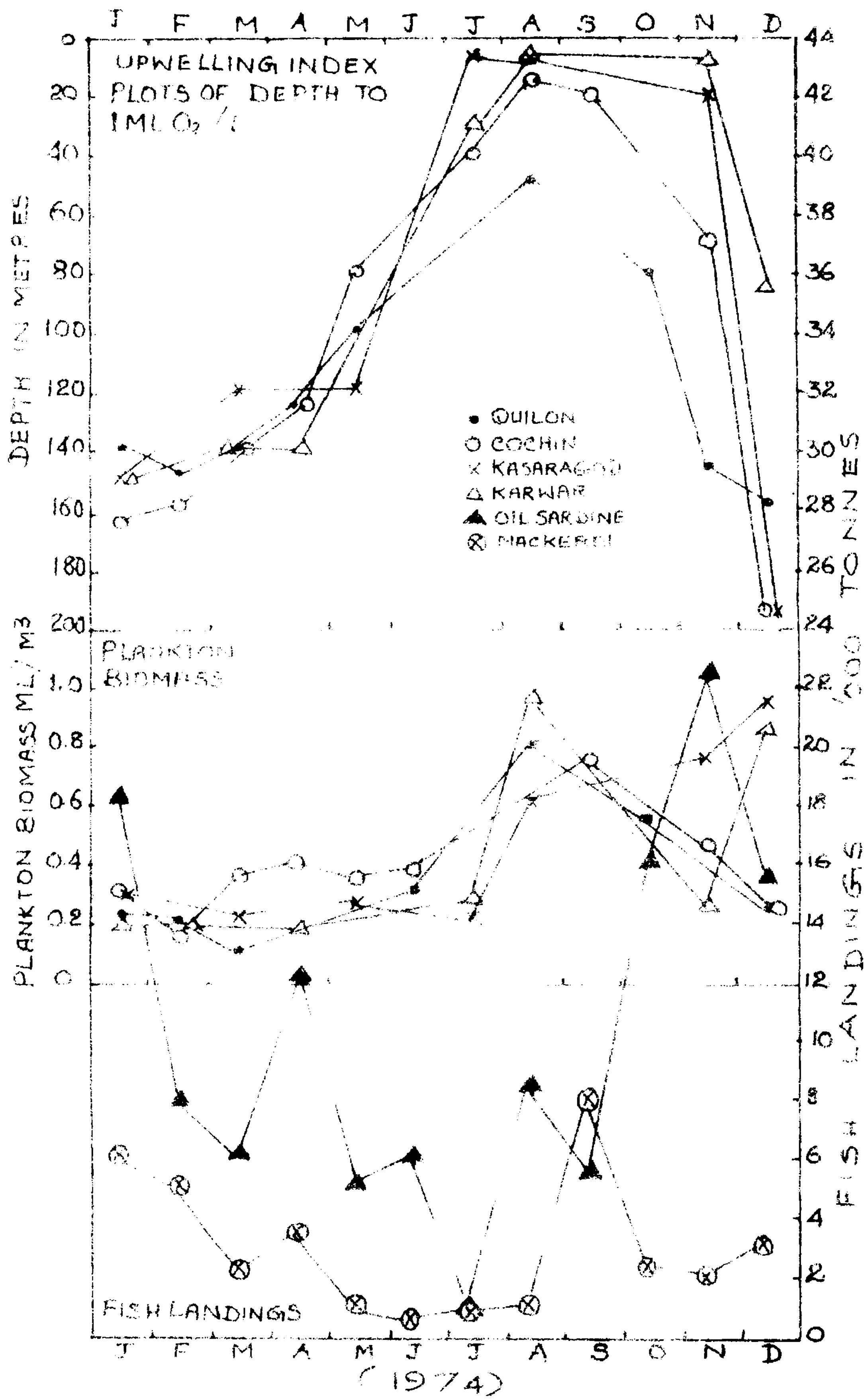
F I G. 16. A

Relationship between upwelling, plankton biomass and landings of oil sardine and mackerel during 1973.


UPWELLING INDEX
PLOTS OF DEPTH 10
1 ML O2/L
DEPTH IN METRES
QUILON
COCHIN
KASARAGOD
KARWAR
PLANKTON BIOMASS
PLANKTON BIOMASS ML/M3
'000 TONNES
IN
FISH LANDINGS
OILSARDINE
MACKEREL
FISH LANDINGS
J F M A M J J A S O N D
(1973)

F I G. 16. B

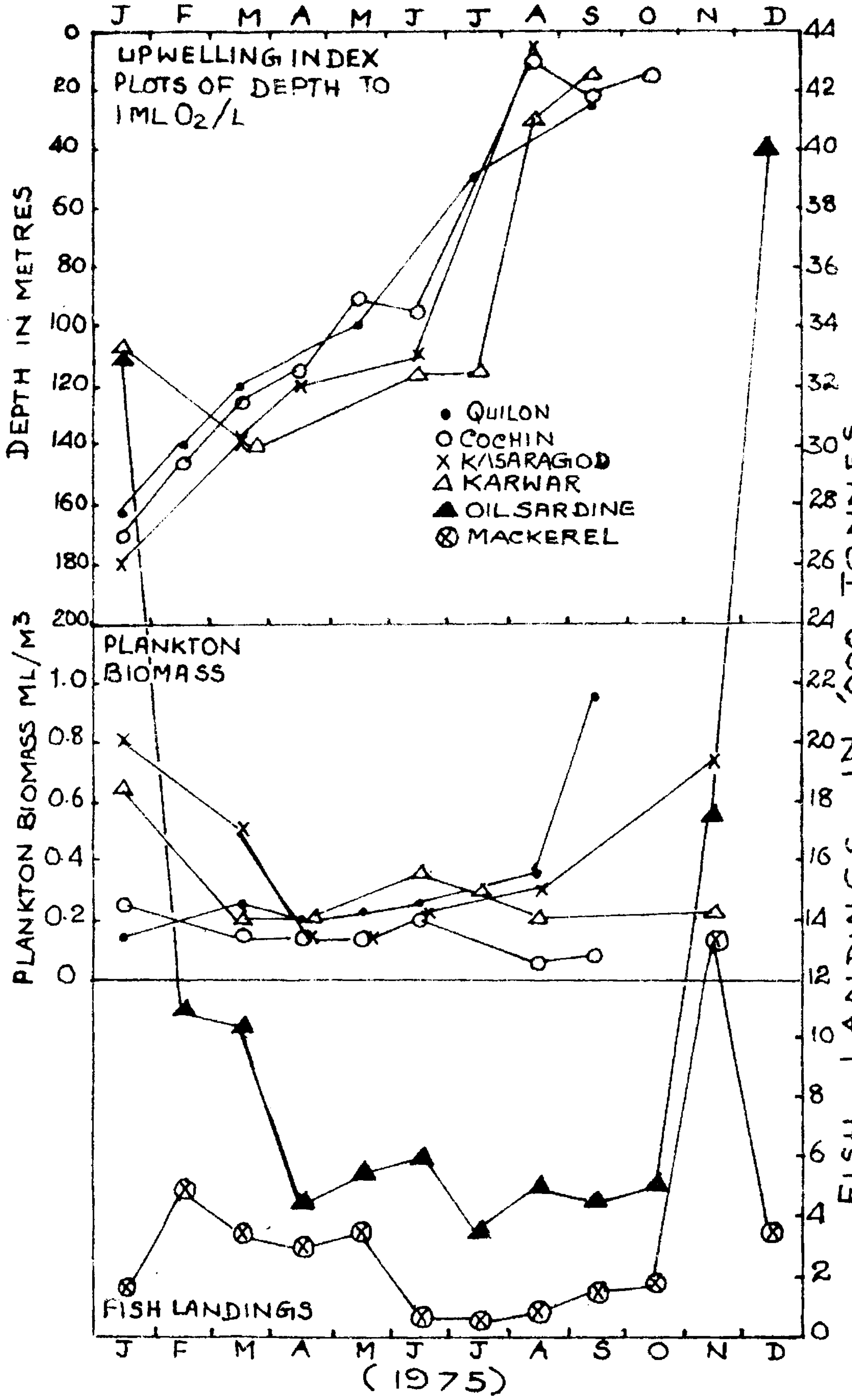
Relationship between upwelling, plankton biomass and landings of oil sardine and mackerel during 1974.



UPWELLING INDEX
PLOTS OF DEPTH TO
1ML $O_2$/L
DEPTH IN METRES
PLANKTON BIOMASS
PLANKTON BIOMASS ML/M3
FISH LANDINGS
FISH LANDINGS IN 1000 TONNES
QUILON
COCHIN
KASARAGOD
KARWAR
OIL SARDINE
MACKEREL
J F M A M J J A S O N D
(1974)

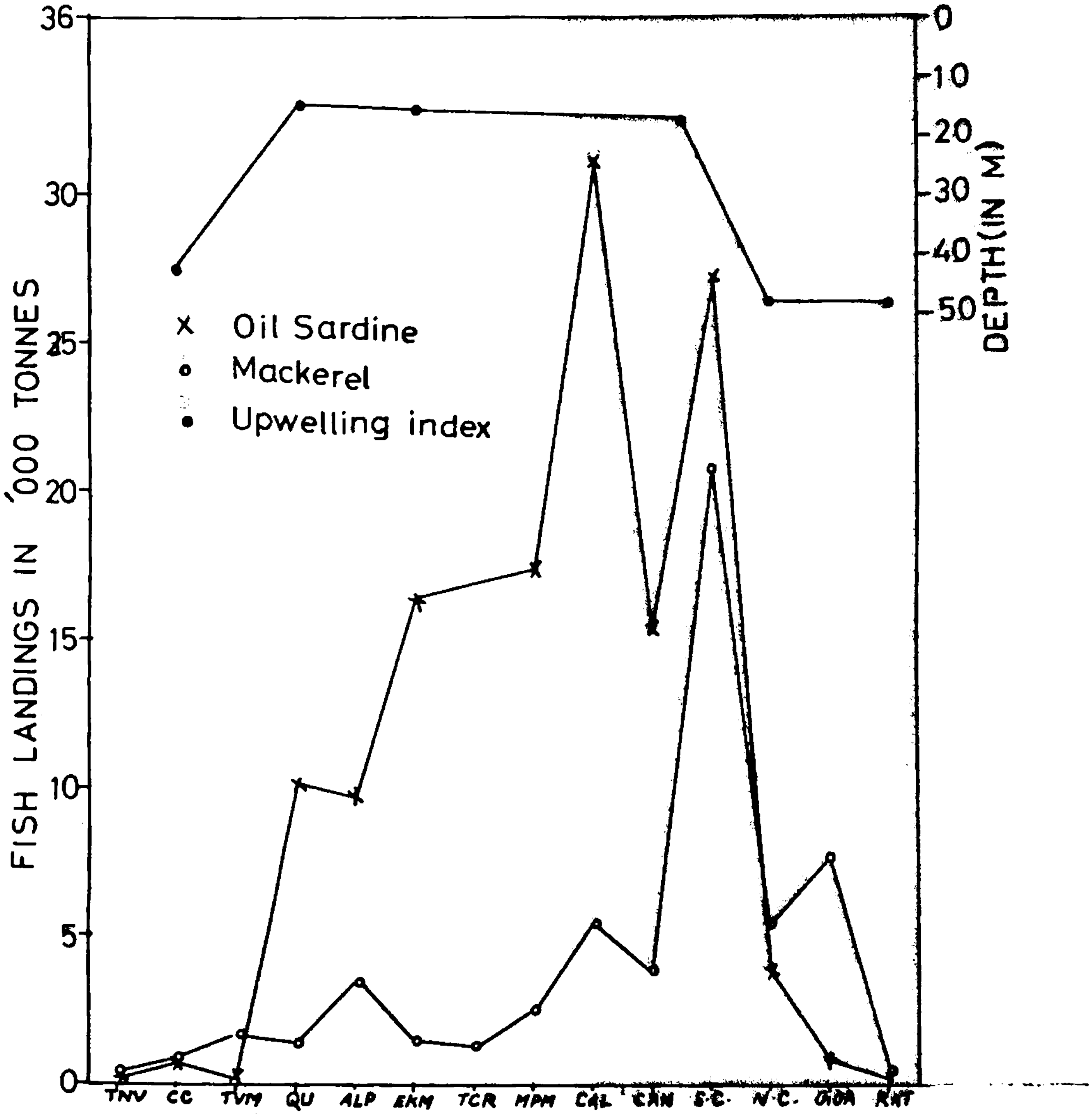
FIG. 16. C

Relationship between upwelling, plankton biomass and landings of oil sardine and mackerel during 1975.


UPWELLING INDEX
PLOTS OF DEPTH TO 1ML O2/L
DEPTH IN METRES
PLANKTON BIOMASS
PLANKTON BIOMASS ML/M3
FISH LANDINGS
FISH LANDINGS IN '000 TONNES
QUILON
COCHIN
KASARAGOD
KARWAR
OILSARDINE
MACKEREL
J F M A M J J A S O N D
(1975)

F I G. 17.

Relationship between upwelling and landings of oil sardine and mackerel in the area between Tinnevely and Ratnagiri during 1977.



FISH LANDINGS IN '000 TONNES
DEPTH (IN M)
36
30
25
20
15
10
5
0
0
10
20
30
40
50
Oil Sardine
Mackerel
Upwelling index
TNV
CC
TVM
QU
ALP
EKM
TCR
MPM
CAL
CAN
S.C.
N.C.
GOA
RAT

running expenses for the craft and the crew. The net result would be a proportionate lowering of prices which in turn would make cheaper fish protein available to low income groups.

## 6. CONCLUSIONS

The most important aspect of the oceanography of the area under study is the prevailing current systems at the surface levels which change their direction from one season to another. The southerly current which develops in May continues until November when the reversal of the current system takes place and the northerly current continues up to April. The southerly current brings comparatively high - saline Arabian sea waters towards south and the northerly current transports the less-saline equatorial waters towards north. The effect of the spreading of the high-saline Arabian sea water towards south is neutralised to a large extent by the south-west monsoon rain and theriver runoff. Hence the annual salinity cycle at the surface levels is dependent on the onset of south-west monsoon and the direction, velocity and duration of the above mentioned southerly and northerly current systems.

The sea water temperature within the area under study shows very wide seasonal and spatial fluctuations. During the south-west monsoon period, when the northern sections exhibit comparatively high temperatures, the situation prevailing in the central and southern sections especially in areas where upwelling is very active, is entirely different. In areas where upwelled water reaches the surface, the sea surface temperature falls considerably much below what could be expected for the season without the influence of the process.

The salinity maximum, characteristic of tropical oceans, was found at depths of 100-150 m. during the north-east monsoon period and between 30-50 m. during the south-west monsoon period. The variations in salinity which are mainly brought about by the influence of rainfall, river runoff and the prevailing seasonal surface currents are characteristic of surface layersa above the salinity maximum layer. The horizontal distribution of salinity during January -March indicate the existence of a convergence zone which was well developed during the year 1974 between Karwar and Ratnagiri with a salinity difference of 2‰. During 1973 the zone, though less developed, was positioned south of Kasaragod.

In general, the shelf waters were well aerated during the major part of the year except during the south-west monsoon season. In August the oxycline became very shallow and in areas of intense upwelling the low oxygen intermediate waters reached the very surface. The oxygen deficient waters remained at surface levels until October, especially in areas where upwelling was intense. By December, once again the shelf waters became well aerated.

Comparatively low values of vertical stability perameter observed at the surface levels during the winter season could very well be indicative of the existence, duration and internsity of the process of sinking. In areas where upwelling was intense, the unstable conditions are more revealed at the bottom levels with a more or less uniform decrease in the vertical stability values.

The process of upwelling is very active in certain localities between Karwar and Cape-comorin. No regularity in the occurrence of upwelling could be observed for any specific locality. The process of upwelling which commence in February at deeper layers continues during the south-west monsoon and the upwelledwater reaches thesurface levels during June-October, depending upon the vertical velocity of upwelling. On an average the vertical velocity observed at different sections rangedbetween 23.cm and 86.cm/ day.

The immdediate effect of the upwelled water reaching the surface is the expulsion of all animal life including fishes from the vicinity as the same is highly oxygen deficient. Dissolved oxygen concentrations of these water masses slowly increase due to the dissolution of atmospheric oxygen which is brought about by wind and wave effects. A spurt in the phyoplankton production leading to a zooplankton bloom sets in areas where bottom waters, rich in nutrients, are brought up to the surface levels as a result of upwelling. The fishery in the area under study for oil sardine and mackerel commences immediately after the south-west monsoon when the zooplankton biomass at the surface layers reaches the peak in areas of effective upwelling.

The process of upwelling is initiated by the prevailing north-east wind system which removed the surface waters away from the coast there by inducing subsurface waters to move towards comparatively shallower depths near the coast. Once the south-west monsoon sets in, the resulting southerly flow continues the induction process with theresult, the sub-surface waters slowly rise towards surface levels, in spite of the south-westerly winds which are not favourable for the process to intensify. Even when the velocity of the southerly current is high, the upwelling process is governed by the vertical stability characteristics of the water column. The monsoon rain and river run-off increase the stability of the water column at the surface levels there by opposing the tendency for the upwelled water to reach the surface.

The vertical time sections for temperature and dissolved oxygen were found to be good indicators of the commencement, intensity and duration of the process of upwelling. The zooplankton biomass, in space and time, proved to be a good indicator of the effect of upwelling on the productivity of the surface waters and the productivity in turn an indicator of the prospects of the ensueing fishery for oil sardine, and mackerel within the area under study.

The process of sinking, which resulted in the spreading of more or less uniform temperature and dissolved oxygen conditions in the sub-surface layers, lead to an increase in the vertical extent of the habitat of major pelagic fish populations within the area under study viz. oil sardine, mackerel and anchovy. As in the case of upwelling, vetical time sections for temperature and dissolved oxygen were found to be good indicators of the commencement,intensity and duration of the process of sinking.

A study on the occurrence, abundance and migrations of oil sardine, mackerel and anchovy based on observations indicated that factors such as the sea water temperature, dissolved oxygen content, salinity characteritics and plankton biomass at surface levels influenced the abundance and seasonal migrations of these fishes. All these fishes avoided areas of intense upwelling activity mainly because of the low dissolved oxygen concentrations and comparatively low temperature conditions. Anchovy is found to move with the changing surface currents and remain within the optimum temperature range avoiding oxygen deficient upwelled water and taking advantage of the prevailing surface currents.

It was found that a prediction system for the major pelagic fisheries in the area could be evolved out of a systematic monitoring of both oceanographic and biological parameters mentioned above. Though qualitative, a direct correlation has been arrived at between the period of intense upwelling and the zooplankton bloom for different sections with a time lag for the completion of the productivity cycle. A similar correlation has been also arrived at between the above factors( upwelling index and zooplankton biomass ) and the fishery for oil sardine and mackerel

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