A STUDY OF THE HYDROLOGICAL FEATURES OF THE SHELF WATERS ALONG THE WEST COAST OF INDIA WITH AN ATTEMPT TO EXPLAIN THEIR INFLUENCE UPON THE LIVING RESOURCES OF THE REGION

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BY

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D E C L A R A T I O N

I hereby declare that the work described in this thesis has been carried out entirely by me and it has not been submitted either wholly or in part by me to any University or Institute for the award of any Degree or Diploma.

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Institute, Cochin.

CERTIFICATE

I hereby certify that this thesis is an authentic record of the work carried out by Shri A. Nandakumar under my supervision at the erstwhile UNDP/FAO Pelagic Fishery Project, Cochin and the Central Marine Fisheries Research Institute, Cochin and that no part thereof has been presented for any other degree in any University.

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

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I wish to express my deep sense of gratitude to Dr. E.G. Silas, Director, Central Marine Fisheries Research Institute, Cochin, for permitting me to continue and complete this work.

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C H A P T E R 1

1 INTRODUCTION

The west coast of India is one of the most productive regions in the Indian Ocean as evident from the fish resources traditionally exploited from these waters. The major pelagic fish resources namely oil sardine, mackerel and bombay duck and a good part of the demersal fish resources, particularly the prawns are well exploited from this area. Therefore, it is needless to stress the importance of the studies on the environmental factors influencing the fisheries.

Before the fifties, only very little work has been done to unravel the environmental factors responsible for this high production in the area. However, some monitoring of physical and chemical characteristics of the inshore waters have been carried out at certain localities as at Calicut by the erstwhile Madras Fisheries Department and the Travancore University. After the establishment of the Indo-Norwegian Project (I.N.P.) in 1953 and the expansion of its activities, sea going research vessels were available for oceanographic work, particularly since late fifties. The I.N.P. vessels R/V Kalava and R/V Varuna conducted quite a large number of research cruises along the west coast of India and collected oceanographic as well as biological samples. The results, obtained thereby enabled to understand the water properties, the general circulation pattern, the different levels of production and the distribution and biomass levels of the fishes.

The hydrological features and biological production of the south-west coast of India are largely dependant on the influence of the monsoons, the associated currents and the upwelling phenomenon.

Apart from the general considerations published on the oceanography of the Arabian Sea and the Bay of Bengal by Sewell (1925, 1935 & 1937), the major contributions to our knowledge of the hydrological features have been made by LaFond (1954, 1957 and 1958), Jayaraman and Gogate (1957), Ramasastry (1959), Banse (1959, 1968), Jayaraman et al (1959), Ramasastry and Myrland (1960), Ramamirtham and Jayaraman (1960), Varadachari (1961), Patil et al (1964), Ramamirtham and Nair (1964), Ramamirtham and Patil (1964), Ramamirtham (1966), Sharma (1966, 1968), Darbyshire (1967), Wooster et al (1967), Reddy and Sankaranarayanan (1968), Lighthill (1969), Sastry and D'Souza (1971), D'Souza and Sastry (1973, 1975) Ramamirtham and Rao (1973) and Murty (1981). Most of the above studies, though conducted in limited periods and in limited areas of the west coast and in the east coast covered as part of the larger programmes like the International Indian

Ocean Expedition (I.I.O.E., 1960-65), helped to accumulate a good amount of information on the oceanography of the region and the basic characteristics of the region have therefore been elucidated by these studies.

It is now clearly known that the surface temperature condition along the south-west coast shows a double oscillation during the year with a primary maximum in April and a secondary maximum in November. Corresponding minima are observed during July/August and in December/January. However the annual range of temperature is not maximum at the surface but at about 100 metres depth. The low temperatures at the surface levels in the monsoon period are the result of the reduction in the insolation due to the cloudy conditions, the monsoon rains and run off waters (Sharma, 1968). The thermocline layer is deepest in winter and shallowest during the summer monsoon (south-west monsoon) when there is a strong upwelling in this region (Murty, 1965; Anon, 1973). In the south-west coast of India the depths of thermocline never exceeded 150 metres depth and that too in January (Sharma, 1966).

The main driving force which brought about the changes in condition within the shelf region is the south-west monsoon and the seasonal currents. The two major current systems, corresponding to the two monsoons bring rapid changes in the water properties. Upwelling brings in cold low oxygenated nutrient laden bottom water to the surface levels which subsequently influence the primary production and the fishery of the region (Murty, 1965; Anon B, 1976).

Ramamirtham and Patil (1964), while explaining in detail, the hydrographic conditions and water mass characteristics along the coast of Cape Comorin-Ratnagiri area for the premonsoon period observed that the latitudinal variations in salinity are quite conspicuous, but temperature variations are not so marked. The salinity maximum is found mostly within the thermocline, with a core of maximum salinity. Banse (1959) observed the annual salinity maximum in the month of January just prior to the reversal of coastal currents. Low values of salinity less than 30.00‰ are observed from north of 10° latitude. Salinity and its seasonal range increase north of Kasaraged (Anon B, 1976).

The shelf waters of the south west coast are generally well aerated during most part of the year with 4-5 ml O_2/L at the surface except during the south-west monsoon upwelling period. Higher values of oxygen in surface waters are noticed in general in June and September and lower values in January and July. Strong vertical gradient of oxygen are present in late summer.

Ramamirtham and Patil (1964) observed that the distribution of density in the vertical plane is clearly resembling that of temperature. The isopycnals move upwards from February or even earlier in the southern sections showing the increase in density at a depth of 100 metres and they reach the surface layers by May. The surface density shows a very wide annual variation with high values in June and October and low values in August and December/January (Sharma, 1968).

Regarding surface currents it is observed that the surface current off the west coast of India is set towards the south from February until late October or November and reversed during the remaining period of the year (Wyrtki, 1963; Banse, 1968). According to Murty (1965) during the monsoon period there is a single stream flowing southward spreading over the entire shelf, while in winter, adjacent to the southerly current which is limited then to the area near to the coast, there is a northerly current. In summer they split into different eddies. The winter stream appears to be stronger and all the currents are stronger at south-west of the coast.

The nutrient concentrations in the near shore regions (within 15 miles) along the west coast of India are generally very high throughout the year. The surface layers are nutrient deficient in the post monsoon period and nutrient rich in the south-west monsoon period. The concentration of nutrients shows a general decreasing trend from south to north along the coast (Reddy and Sankaranarayanan, 1968).

Considerable amount of work has been done by various workers to study the influence of environmental factors on the living resources of the region, mainly on plankton and fishes along the west coast of India. Mention is to be made of the contributions of Chidambaram and Menon (1945), Carruthers et al (1959), Banse (1959, 1968), Subramaniam (1959, 1972), Pradhan and Reddy (1962), Murty (1965), Sankaranarayanan and Qasim (1968), Murty and Edelman (1970), Rao et al (1973), Sharma and Murty (1973) and Prabhu et al (1974).

Generally, low values of zooplankton biomass have been noticed in the shelf from January to April. Afterwards the peak was reached in July-September. A shoreward shift in zooplankton was observed until December in the southern areas. The peak period of occurrence of zooplankton biomass along the coast have been found closely following the peak period of upwelling (Menon and George, 1977).

The fisheries of oil sardine and mackerel, the two major resources from the coastal waters of the west coast of India, start after the commencement of the south-west monsoon by July-August. The fishing season for both the species end by March-April with peak abundance noticed in October-December period (Jhingran, 1975; Anon A, 1976). Both the species appear first in the southern part of the Kerala coast at the start of the season and gradually advance to the northern parts by the north setting current in October (Panikkar, 1952; Anon A, 1976). Oil sardine is abundant between Alleppey-Karwar area (Balan and Raghu, 1979) while 90% of the mackerel catches are from the Quilon-Ratnagiri region (Noble, 1979). The distribution and abundance of these species are closely associated with the variations in the water properties caused mainly by the general wind-driven current patterns along the coast as well as the sequence of upwelling phenomenon.

The present studies conducted systematically, covering especially the shelf waters of the Cape Comorin-Ratnagiri region (8°N to 17°N) in the west coast of India, document the results of one of the best time series (1972-'75) observations on the oceanographical conditions in the area in recent times. While consolidating the general points of information and the conclusions projected by the earlier workers the studies also elucidated further, the seasonal synoptic picture of the hydrological conditions.

The influence of the hydrological factors on the living resources of the area, particularly on the zooplankton and the two major pelagic fisheries is also dealt with.

CHAPTER 2

2 MATERIAL AND METHODS OF ANALYSIS

The data and material for the present studies have been availed from the UNDP/FAO Pelagic Fishery Project which functioned at Cochin, during 1972 - '78 period. The Project worked with two research vessels, R/V Rastrelliger (46.5 m/152') and R/V Sardinella (16.34 m/54'). The author of the thesis has been involved in the field data collection and laboratory analysis, while working in the oceanographic discipline of the Project throughout its period of functioning. The hydrological studies conducted by the Project along the south-west coast of India have been based on samples collected from stations along the different fixed sections worked from September 1971 to 1978 with the above two vessels and partly also by R/V Varuna (28 m/91') of the Integrated Fisheries Project, Cochin in 1972.

The hydrographic data limited to the years 1972 to 1975 have been treated in the thesis. The data were collected from the shelf waters of six different sections, namely Cape Comorin, Quilon, Cochin, Kasaragod, Karwar and Ratnagiri along the west coast of India. The stations along each section were fixed 10 nautical miles apart. The station close to the coast was at around 15 metres depth. The station positions in each section are given in Fig. 1 and the number of coverages in each year for different sections are presented in Table 1.

The water samples were collected from standard depths at each station using Nansen reversing water bottles. Temperature data have been recorded from both main and auxiliary thermometers fitted in duplicate to the reversing water bottles and the appropriate corrections were incorporated from the correction charts provided along with the thermometers. Water samples were collected separately for the analysis of salinity and dissolved oxygen content. Salinity values were obtained by using a salinometer. Dissolved oxygen values were estimated by titration using classical Winkler method (Strickland and Parson, 1965). Density (Sigma-t) values were obtained from standard nomograms.

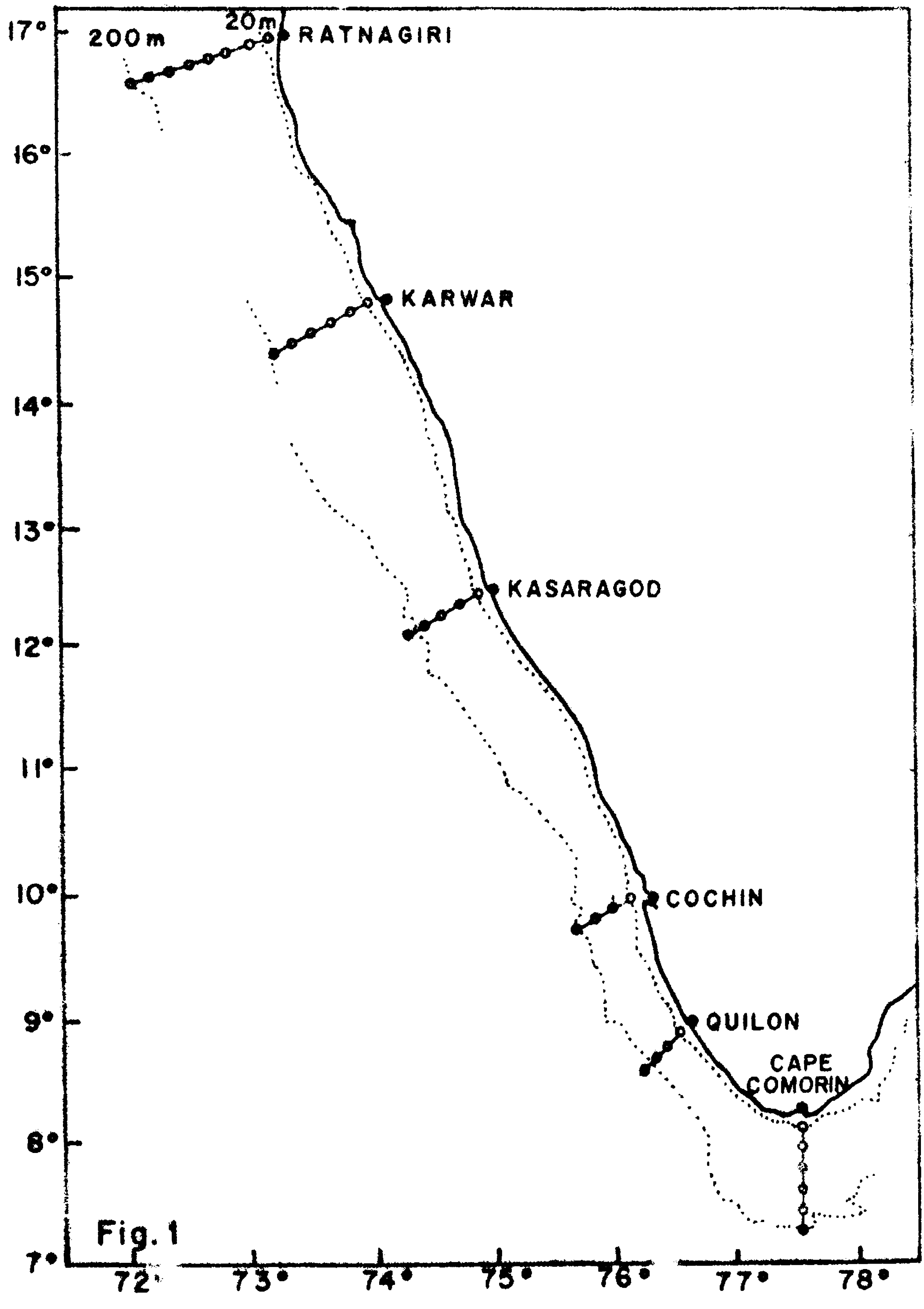
The zooplankton data used in the thesis for the correlation studies have also been taken from Pelagic Fishery Project records. These materials were collected from the corresponding hydrographic stations at all the sections under study and the zooplankton volumes were estimated in ml/m^3 of water filtered. The state-wise quarterly landing data for oil sardine and mackerel were availed from the records of the Central Marine Fisheries Research Institute, Cochin.

Table-1. Number of coverages of different sections during 1972-75

Sections	1972	1973	1974	1975
Cape Comorin		5	7	6
Quilon	8	7	7	5
Cochin	11	7	9	8
Kasaragod	9	7	7	5
Karwar	8	7	7	5
Ratnagiri	5	5	7	5

FIGURE 1

Map showing the location of stations at different sections along the west coast of India.


200m
20m
RATNAGIRI
KARWAR
KASARAGOD
COCHIN
QUILON
CAPE COMORIN
17°
16°
15°
14°
13°
12°
11°
10°
9°
8°
7°
72°
73°
74°
75°
76°
77°
78°
Fig. 1

CHAPTER 3

3 VERTICAL VARIATIONS OF THE HYDROLOGICAL CONDITIONS OF THE SHELF WATERS OFF THE WEST COAST OF INDIA

The vertical distributional characteristics of temperature, salinity, density and dissolved oxygen of the six sections worked have been presented based on the observations during a typical year (1974) chosen for its complete and more frequent coverage. Vertical section diagrams are given for all the above parameters for the different sections dealt with.

3.1 Off Cape Comorin

Temperature (Fig.2):

In the month of February the upper 100 metre layer within the shelf off Cape Comorin showed temperature ranging between 26.08 - 26.97°C. Temperature values at all standard depths within the shelf were found to be within 22.00- 27.00°C. By April, high values of temperature were recorded within the shelf with surface values ranging between 28.40 - 29.80°C and comparatively higher temperature was observed nearer to the edge of the shelf. Though the upper layer temperature showed higher values during April when compared to February conditions the

FIGURE 2

Vertical sections of temperature off Cape Comorin for different months (1974).

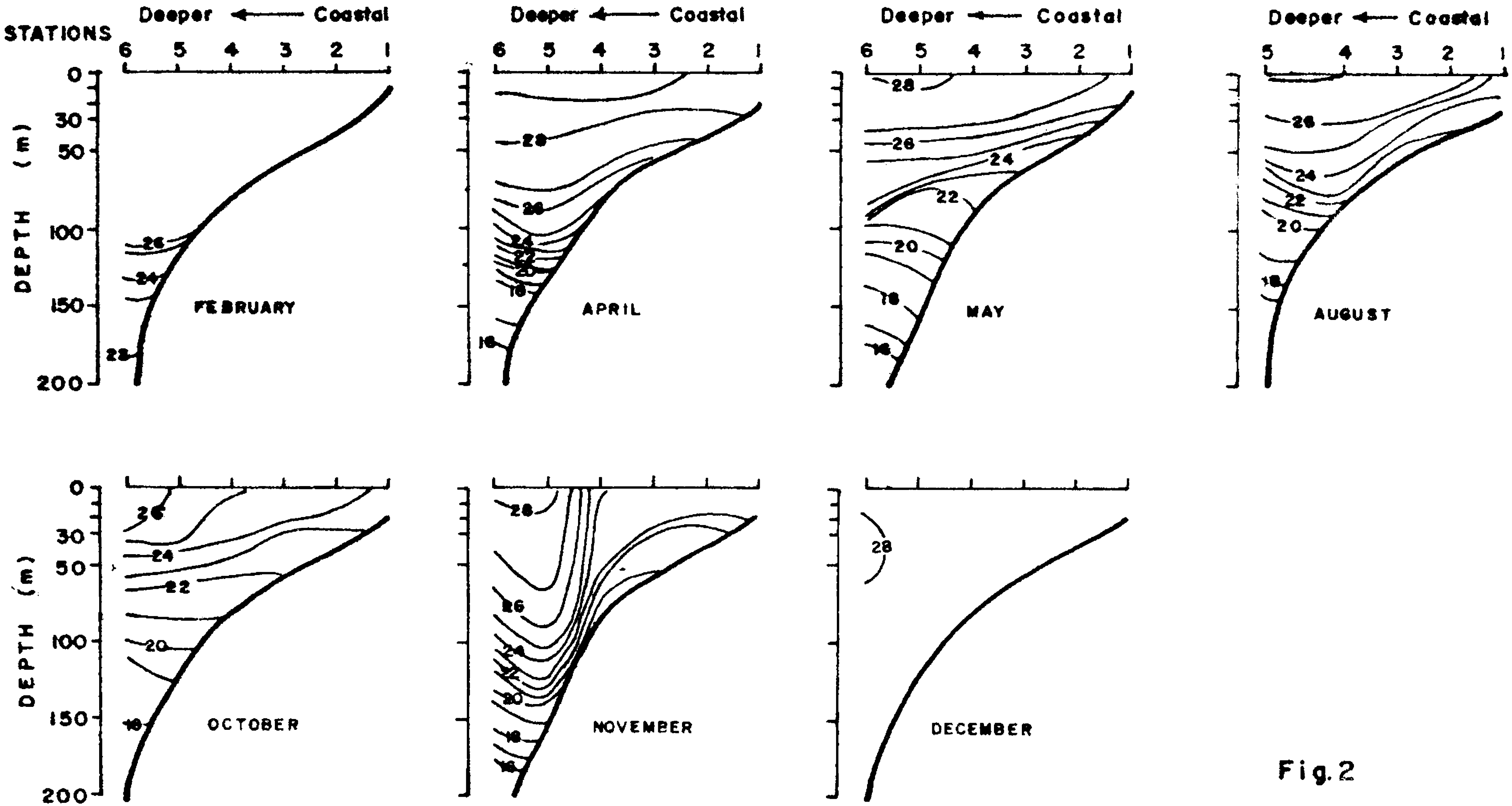

STATIONS
Deeper ← Coastal
DEPTH (m)
FEBRUARY
APRIL
MAY
AUGUST
OCTOBER
NOVEMBER
DECEMBER

Fig. 2

deeper layers recorded a temperature decrease of about 4-6°C at all depths below 125 metre within the shelf. By May, again the temperature conditions showed gradual decrease at all depths within the shelf in general, and near to the coast in particular, where values below 27.00°C were recorded. There was a temperature fall of 1-3°C within the upper 50 metre layer. The temperature fall was found to be maximum within 75 - 125 metre depth zone. By August, the temperature at surface close to the coast was found to be 24.70°C. The temperature fall at surface near to the coast and at subsurface layers further offshore is clearly indicated in the vertical section diagram for August by the tilting of the isotherms towards the coast. The isotherms were further found tilting upwards, in the subsequent months also there by decreasing the temperature at all depths. This was much pronounced in November and all the isotherms were found shifting steeply unpards decreasing the temperature to values below 24°C at all depths upto the middle of the shelf. Considerable changes were observed in the temperature pattern of December with temperature ranging between 27.00 - 28.00°C within the shelf. The lower temperature conditions within the shelf completely disappeared and temperature showed increase at all depths.

Salinity (Fig.3):

The salinity values were found to be below 33.00‰ near the coast in the month of February. Salinity increased seaward at all depths. Thus, at around 100 metre depth salinity values were about 35.00‰ in April. The upper 30 metre layer salinity remained below 34.00‰ but the values near to the endge of the shelf at this depth zone were comparatively higher. The 35.00‰ salinity isoline lifted upwards to depths of 60 - 80 metres within the shelf in April. The salinity values considerably increased in the month of May at all depths. The upper layer salinity showed decrease in the month of August but the low salinity conditions observed in May near to the edge of the shelf continued to remain unchanged. In November, salinity values were very low and the distribution pattern indicated the influence of low salinity water at surface and near to the coast. The spreading of the low salinity water (salinity below 33.00‰) seaward was observed in the vertical section diagram for salinity. The upper 75 metre layer remained less saline (between 33.00 - 35.00‰) in the month of December.

Density (Fig.4):

The density (sigma-t) values ranged between 21.64 -

FIGURE 3

Vertical sections of salinity off Cape Comorin for different months (1974).

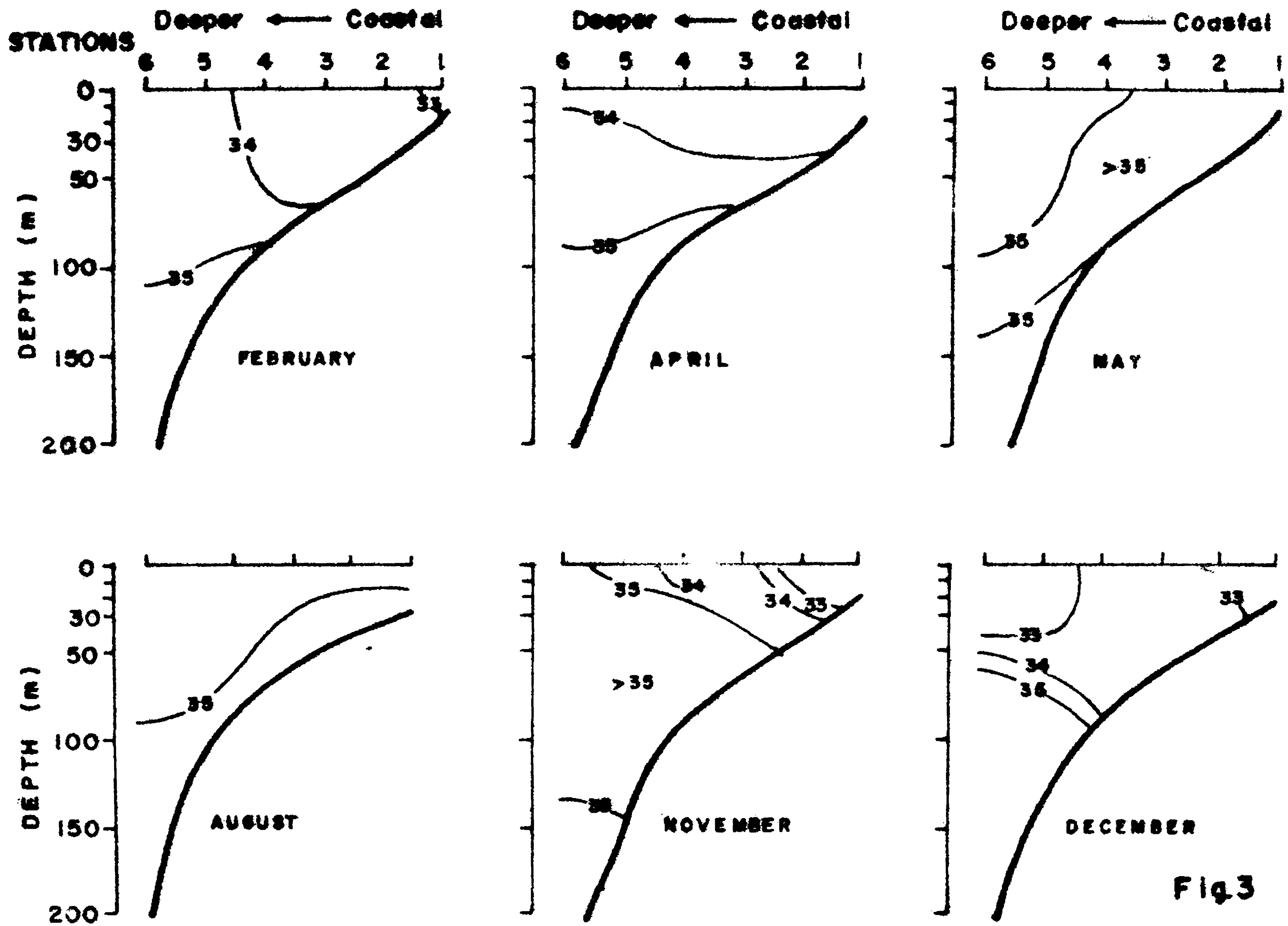

STATIONS
Deeper ← Coastal
DEPTH (m)
FEBRUARY
APRIL
MAY
AUGUST
NOVEMBER
DECEMBER
>35

Fig.3

FIGURE 4

Vertical sections of density off Cape Comorin for different months (1974).

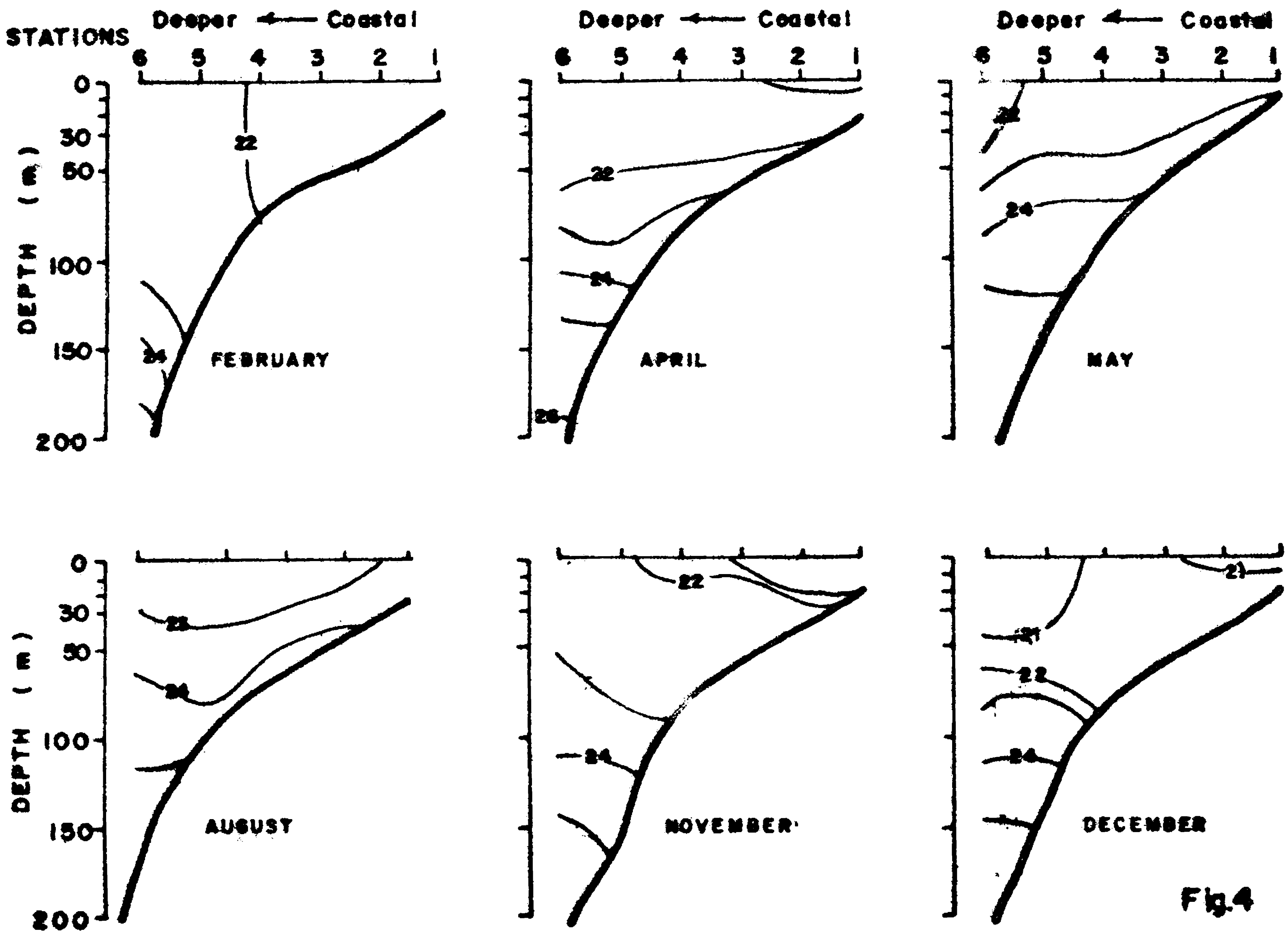

STATIONS
Deeper ← Coastal
6 5 4 3 2 1
DEPTH (m)
0
30
50
100
150
200
22
24
26
FEBRUARY
APRIL
MAY
AUGUST
NOVEMBER
DECEMBER
21

Fig.4

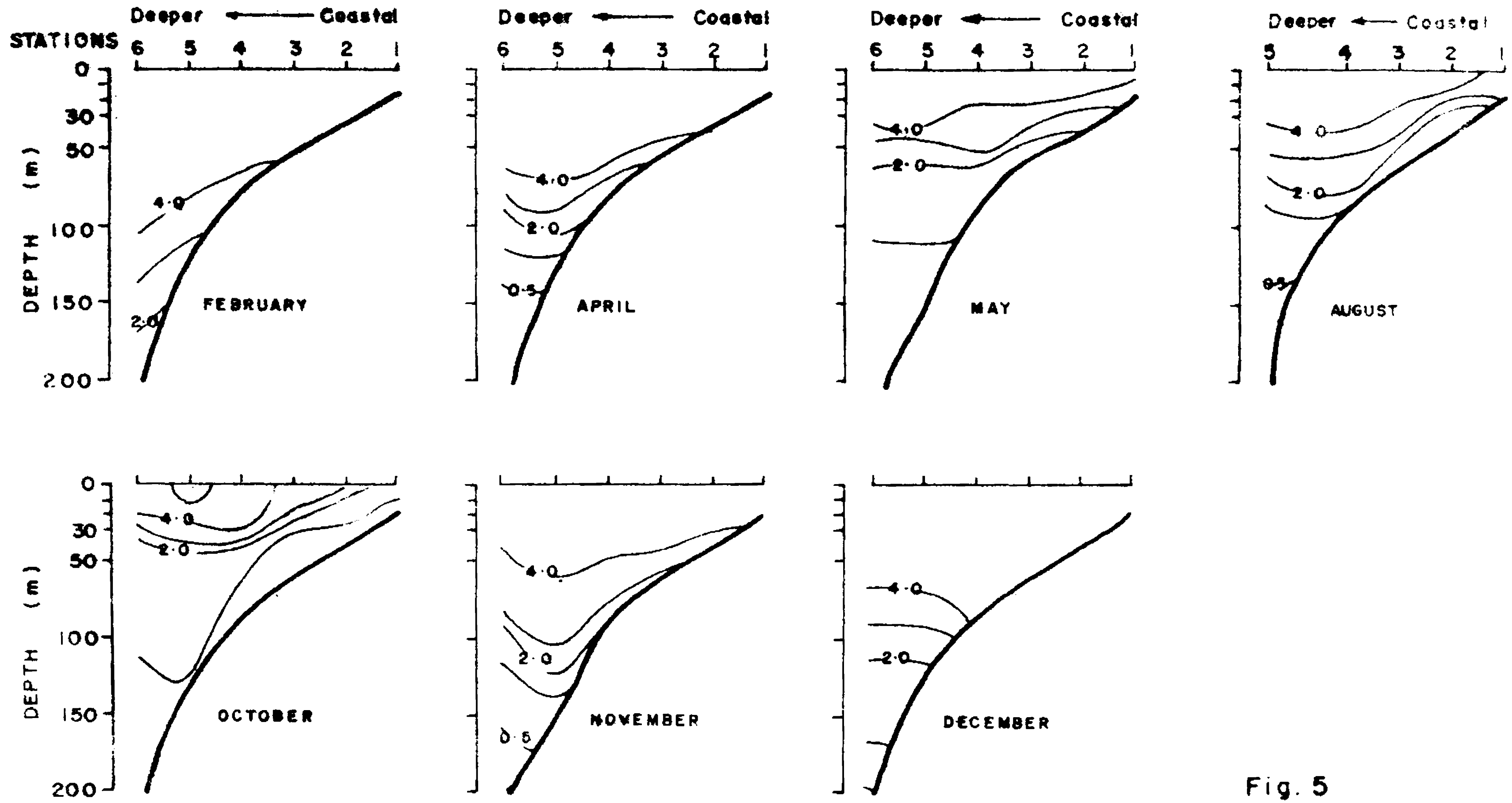
22.37 in the upper 100 metre depth column within the shelf during February. Sigma-t values at all depths upto the middle of the shelf were below 22.00, with denser water located beyond the middle of the shelf. Higher density water intrusion to the shelf was observed in April as indicated by the appearence of denser water of sigma-t value 26.00, at depths around 200 metre near to the edge of the continental shelf. Density at all depths increased considerably in the month of May indicated by higher sigma-t values within the shelf. By August the surface layers near to the coast and the subsurface layers below 30 metre within the shelf recorded density all above 23.00. Comparatively denser water was observed within the shelf during this month. Density decreased by November, and low density water (sigma-t value, below 21.00) was observed near to the coast. The decrease in density continued in the month of December also at all depths upto 100 metres. Comparatively lower density water (sigma-t value below 21.00) was observed within the upper 50 metre depth column during this period.

Dissolved oxygen (Fig.5):

The upper layers upto a depth of 50 - 100 metres recorded dissolved oxygen values above 4.00 ml/L in the month of February. The upper layers were all well aerated

FIGURE 5

Vertical sections of dissolved oxygen off Cape Comorin for different months (1974).



STATIONS
Deeper ← Coastal
DEPTH (m)
0
30
50
100
150
200
FEBRUARY
APRIL
MAY
AUGUST
OCTOBER
NOVEMBER
DECEMBER
4·0
2·0
0·5

Fig. 5

in this month and the pattern continued to remain unchanged till April. The appearance of 0.5 ml O_2/L layer at a depth of about 150 metres within the shelf and the lowering of dissolved oxygen values at all depths below 100 metres indicated the intrusion of low oxygenated water towards the shallow coastal waters. These waters further moved upwards and by May the dissolved oxygen values at subsurface layers showed further decrease. By August the coastal stations recorded values below 4.00 ml/L and the pattern of decreasing trend continued to persist. Dissolved oxygen values dropped down considerably in the month of October and at surface, values below 2.00 ml/L were recorded at the coastal stations. The entire bottom within the shelf was covered with poorly oxygenated water (below 1 ml/L) at this time. By November the upper 50 metres layer was well aerated and the lower values observed at the coastal stations disappeared. December pattern showed further increase in the dissolved oxygen content of the waters upto depths below 50 metres.

3.2 Off Quilon

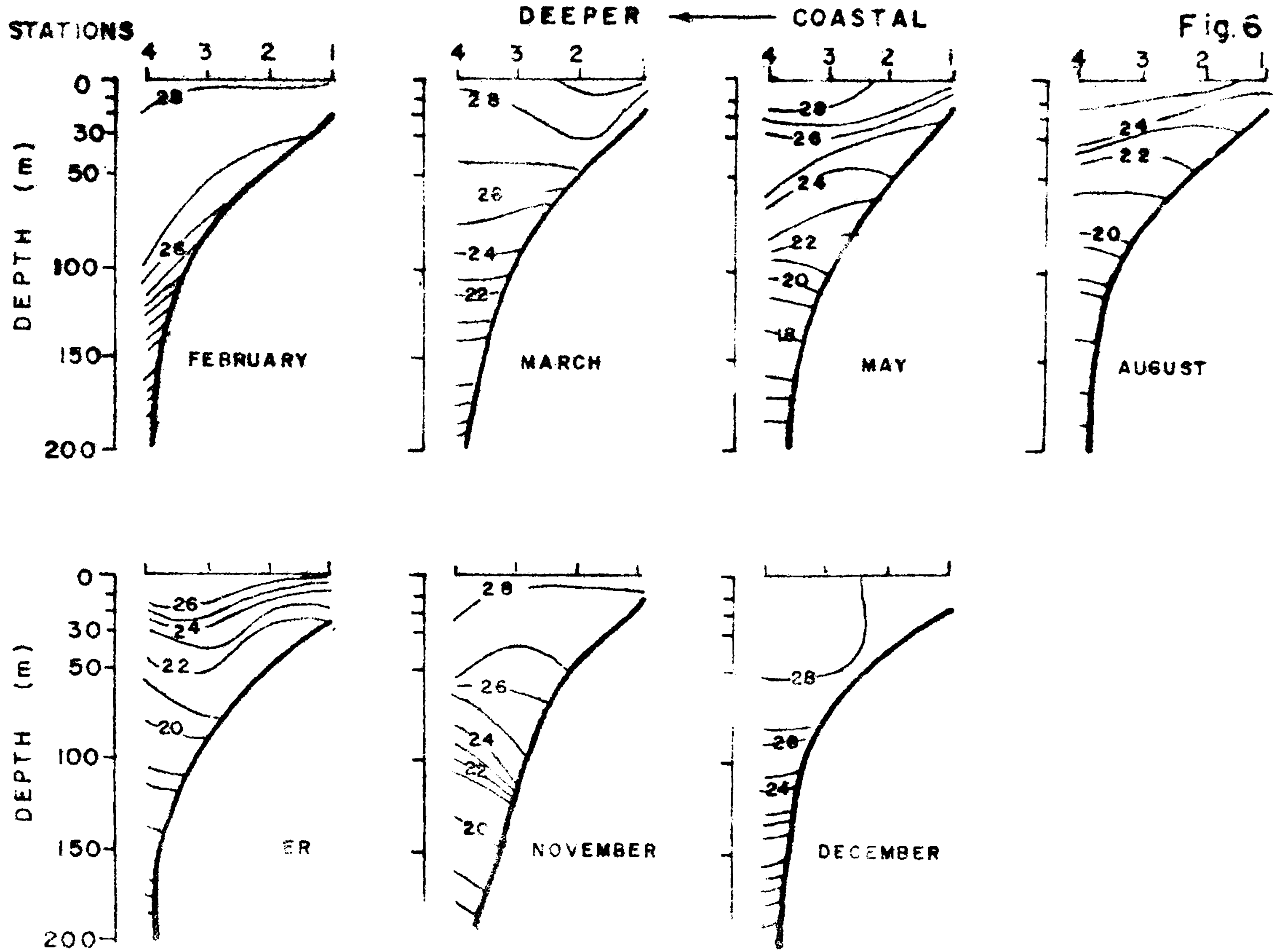
Temperature: (Fig.6):

Temperature at surface layers was above 28.00°C in the month of February and values showed an increasing trend towards deeper stations. Depth of isothermal mixed layer also increased towards deeper stations. Thus the mixed layer depth extended upto 100 metres at the station situated near to the edge of the shelf. The isotherms were found tilting towards the shore indicating colder water intrusion towards the shallow coastal area. The temperature within the upper mixed layer ranged between 27.10 - 28.35°C. The temperature increased at all depths in the month of March. Comparatively warmer water was observed at surface near to the coast, with temperature values above 29.00°C. The vertical tilting pattern of the isolines disappeared in March and they were found almost parallel to each other. The distribution in the upper layers for the month of May showed the presence of lower temperature water near to the coast with temperature decreasing at all depths. By August the entire shelf water became colder and temperature values below 25.00°C were recorded at surface near to the coast. The surface layer temperature within the shelf varied between 24.60 - 26.90°C with gradual increase of surface temperature at deeper stations. The 24°C isotherm normally found at a depth about 100 metres in March uplifted to a depth of about 20 metres in August. The surface water temperature of the coastal stations increased by October with increase of temperature at upper layers throughout the shelf. In October, though

FIGURE 6

Vertical sections of temperature off Quilon for different months (1974).

Fig. 6



DEEPER ← COASTAL
STATIONS
4 3 2 1
DEPTH (m)
0
30
50
100
150
200
28
26
24
22
20
18
FEBRUARY
MARCH
MAY
AUGUST
ER
NOVEMBER
DECEMBER

the temperature showed increase at upper layers, decrease was observed at subsurface levels in offshore areas. The temperature at the surface layers were all above 28.00°C in the month of November and the distribution pattern indicated increase of temperature in the coastal stations with lower temperature water retreating from the shelf. The temperature distribution pattern of December indicated comparatively warmer water (temperature above 28.00°C) within the upper 50 metre depth layer except for the coastal stations, where the temperature was comparatively low. The isotherms were seen parallel and the mixed layer extended well below 75 metres in December.

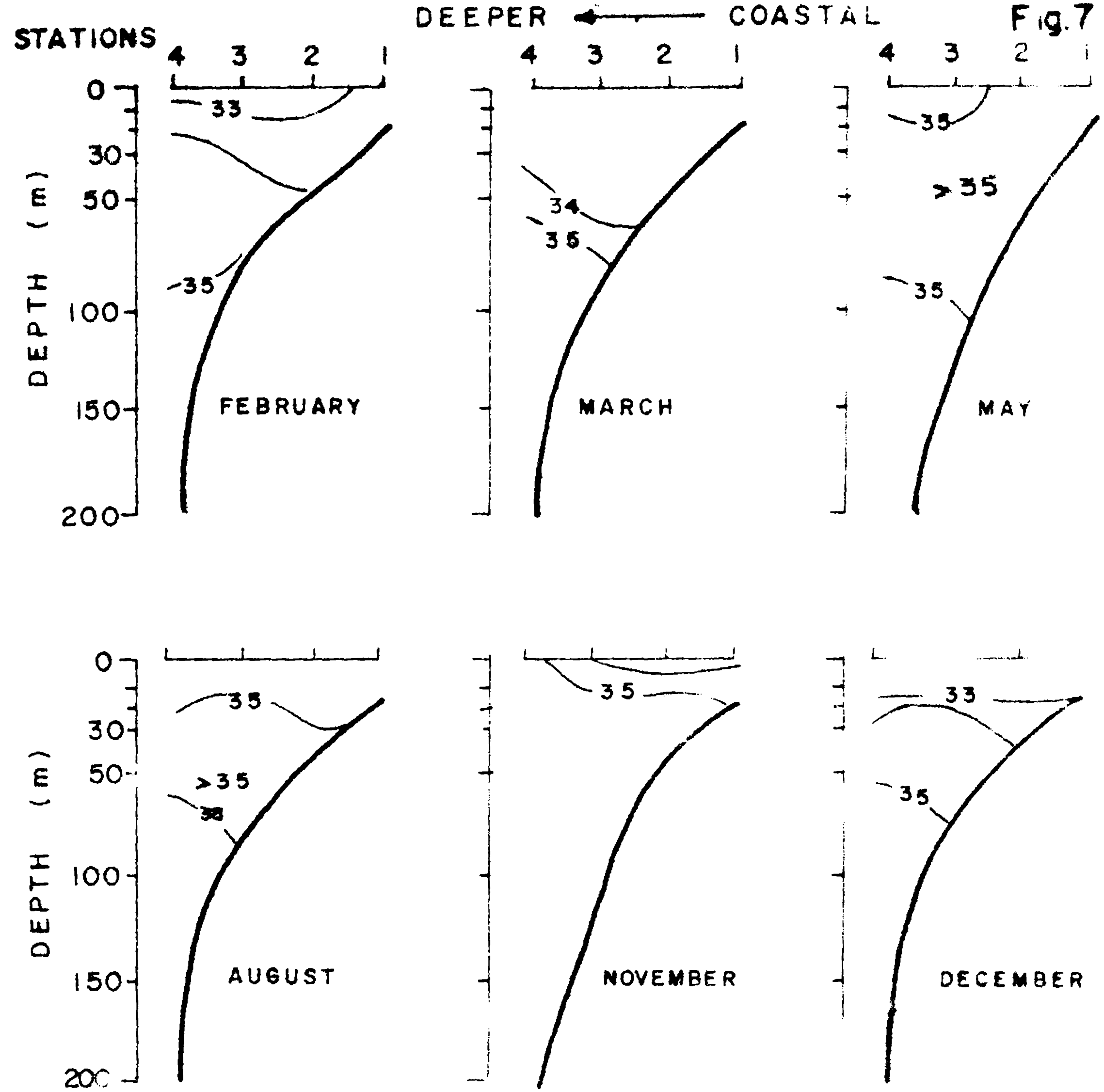
Salinity (Fig.7):

The surface salinity values were below 33.00‰ in the month of February. Salinity values showed gradual increase towards bottom at all stations. The shelf waters near to the coast recorded comparatively higher salinity with values ranging between 33.00 - 34.00‰. Salinity values within the upper 30 metre layer showed increase at all depths, by March and further increase in salinity was observed in the month of May. Except for the surface layers of the deeper stations salinity values were all above 35.00‰ within the upper 75 metre depth zone and

FIGURE 7

Vertical sections of salinity off Quilon for different months (1974).

Fig.7



DEEPER ← COASTAL
STATIONS
4 3 2 1
DEPTH (m)
0
30
50
100
150
200
33
35
34
>35
FEBRUARY
MARCH
MAY
AUGUST
NOVEMBER
DECEMBER

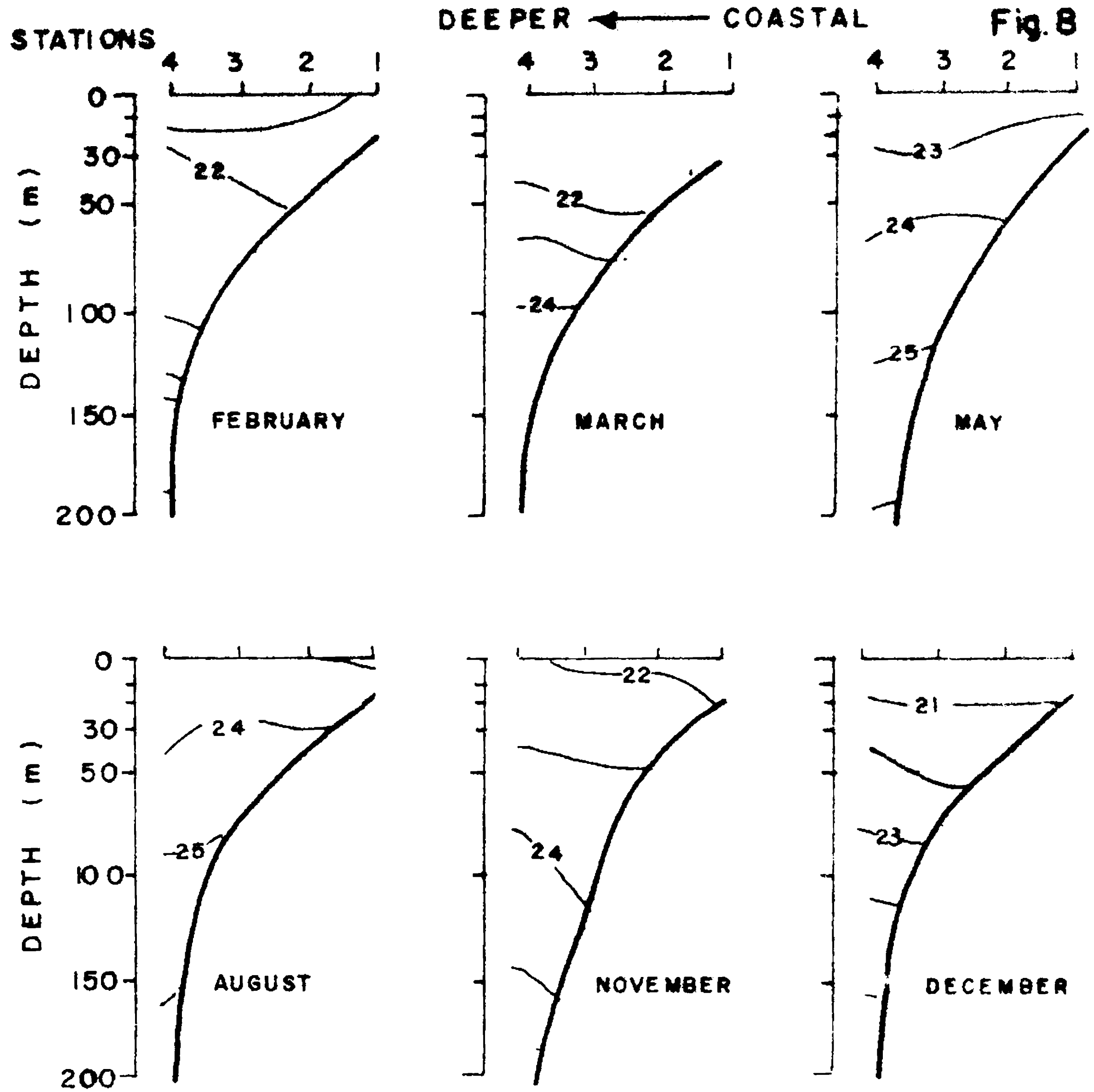
below this the salinity values were gradually decreasing with increase in depth. During August salinity values at 30 - 75 metre depth layer were found to be above 35.00‰. Salinity values at upper layers gradually decreased to values below 34.00‰ in the month of November and below 33.00‰ in the month of December. The salinity variations during August-December period were mainly confined to the upper 50 metre depth layer, whereas below this depth zone the salinity did not show much variations.

Density (Fig.8):

Higher density water was observed near to the coast in the month of February and the density at surface layers decreased seaward. The sigma-t values were all below 23.00 in the upper 100 metre layer within the shelf and except for stations close the coast, values were all below 21.00 in the upper 20 metre depth layer. Density showed gradual increase towards bottom. Density further decreased by March at all depths in the upper layers to values below 22.00 within the upper 40 to 50 metre depth layer. Below this layer slight increase was observed in density and by May the values in the upper 20 to 30 metre depth layer were all above 23.00 with the coastal stations recording comparatively higher density conditions. The increase of density in the subsurface layers observed in May continued till

FIGURE 8

Vertical sections of density off Quilon for different months (1974).



STATIONS
DEEPER ← COASTAL
4 3 2 1
DEPTH (m)
0
30
50
100
150
200
22
24
23
25
21
FEBRUARY
MARCH
MAY
AUGUST
NOVEMBER
DECEMBER

Fig. 8

August. The density values at all depths showed considerable increase in August with comparatively higher density conditions prevailing within the shelf. Except for the surface layers close to the coast, the values were all above 24.00 in the upper 30 to 50 metre depth zone with density showing increase below this layer. But considerable decrease in density was observed in November and at stations close to the coast values below 22.00 were recorded with the higher density isolines moving to the deeper layers. Density values further decreased at all depths within the shelf in December when the annual minimum values were recorded.

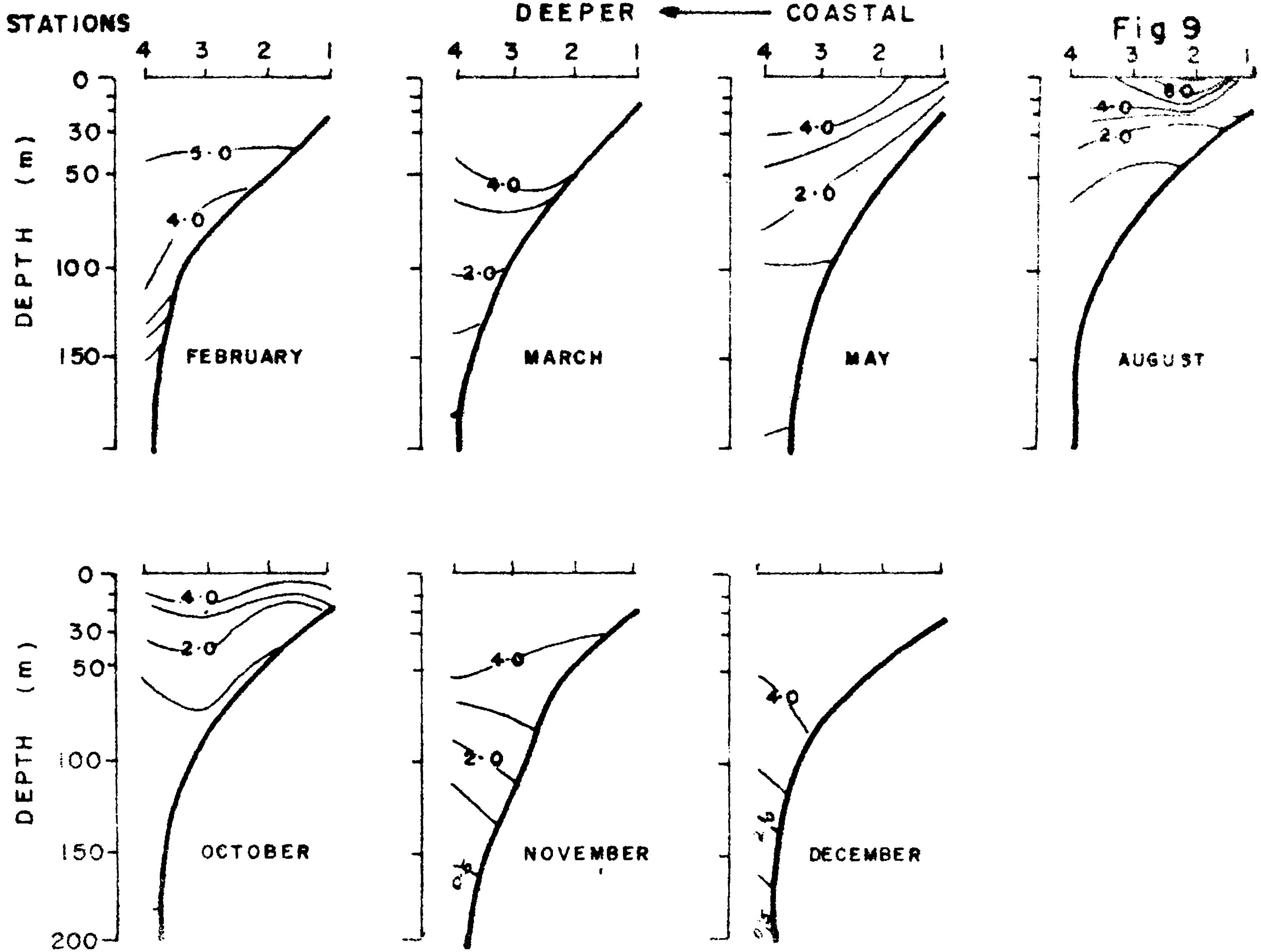
Dissolved oxygen (Fig.9):

The upper 30 metre layer with the shelf in the month of February was covered with well oxygenated water of oxygen content above 5.00 ml/L. The isolines of dissolved oxygen content indicated the vertical ascent of the low oxygen waters towards the coast. The 1 ml O_2/L layer was found at a depth of about 150 metres in the month of February. By March the values showed gradual increase at all depths and the entire upper 50 metre layer recorded dissolved oxygen content above 4.00 ml/L. An upward shift of the low oxygenated water was observed with the 1 ml O_2/L layer at a depth around 125 metres. Considerable

FIGURE 9

Vertical sections of dissolved oxygen off Quilon for different months (1974).

Fig 9


STATIONS
DEEPER
COASTAL
DEPTH (m)
FEBRUARY
MARCH
MAY
AUGUST
OCTOBER
NOVEMBER
DECEMBER
5·0
4·0
2·0
8·0

amount of low oxygenated water intrusion towards the coast was observed in the month of May. At surface close to the coast 3.28 ml O_2/L was observed and values above 4.00 ml/L were recorded near to the edge of the shelf only. Further upliftment of the isolines were observed with 1 ml/L layer uplifting to depths around 50 metres. The presence of low oxygenated water continued to persist in the month of August also and at surface layers within the middle of the shelf regions values above 7 ml/L were also recorded. Least depth of occurrence of 1 ml O_2/L layer was found ascending 50 - 70 metre depth level in the month of October. Dissolved oxygen content values at surface layers upto 50 metres remained above 4.00 ml/L in November, with values ranging between 4.03 - 4.86 ml/L. The 1 ml O_2/L oxygen layer was observed at around 80 - 120 metre during this period. Almost the same pattern of distribution was observed in the month of December also and the lower values were found gradually retreating from the shelf.

3.3 Off Cochin

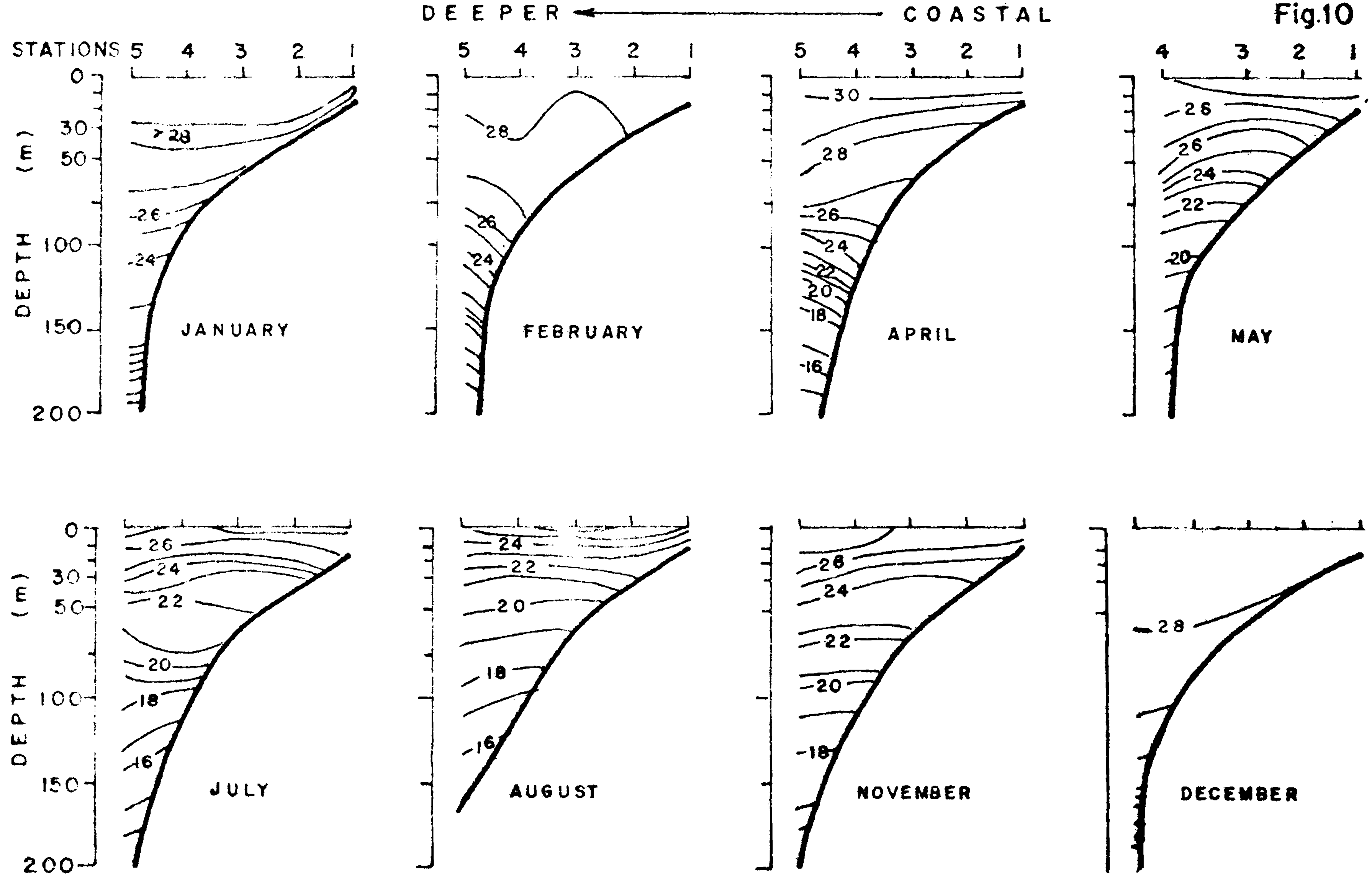
Temperature (Fig.10):

In the month of January the temperature at the upper 30 metre layer varied between 27.70 - 28.10°C. The temperature showed slight increase at 30-50 metre depth zone with values above 28.00°C. The isotherms were found gradually shifting upwards, as it approached nearer to the shore. By about February temperature showed increase at all depths in the upper 30 metre layer and further below, it showed gradual decrease. The isotherms below 75 metres further shifted upwards in the month of April but the surface water grew warmer with the coastal stations recording comparatively higher temperature. The upper 10 metre layer temperature within the shelf varied between 30.00 - 30.90°C but by May the surface temperature decreased to values below 29.50°C with temperature gradually decreasing towards offshore stations. Temperature at all depths also decreased considerably during this period. By about July the surface water temperature further lowered and the 26°C isotherm normally found below 75 metres during January-April period, uplifted to a depth around 10--20 metres. The upper layer temperatures were below 27.00°C and the lowest temperature was observed in the Cochin section during August with the surface temperature near to the coast being 25.8°C. In the upper 30 metre layer within the shelf the temperature varied between 26.80 and 21.72°C. The temperature showed an increase of about 2°C at all upper layer depths in November, when compared to August. The depth of mixed layer extended upto 50 metres in the month of December with considerable increase in

FIGURE 10

Vertical sections of temperature off Cochin for different months (1974).

Fig.10


DEEPER
COASTAL
STATIONS
DEPTH (m)
JANUARY
FEBRUARY
APRIL
MAY
JULY
AUGUST
NOVEMBER
DECEMBER

temperature at all depths. Thus the temperature within the upper 50 metre depth layer varied between 28.00 - 28.40°C in December.

Salinity (Fig.11):

The upper layers within 10 metre showed the presence of low salinity water below 33.00‰ in the month of January and salinity values increased towards deeper depths. Very low salinity of 18.37‰ was observed close to the coast. Salinity values at all depths showed increase in February with the coastal stations recording the presence of low salinity water. During April, salinity values showed increase at all depths upto 50 metre with comparatively higher salinity close to the coast. Salinity values continued to increase at all depths in May also with the values at surface layers being slightly lower than 35.00‰. Below 50 metres salinity showed decrease towards bottom. The salinity values in the upper 10 metre layer showed increase in July, while below this depth zone salinity showed decrease with increase in depth. During August very low salinity values (salinity below 30.00‰) were recorded close to the coast at surface layers and these waters were found spreading to seaward. The salinity values close to the coast at surface was 30.00‰. Except for the stations close to the coast at 15 metre depth

FIGURE 11

Vertical sections of salinity off Cochin for different months (1974).

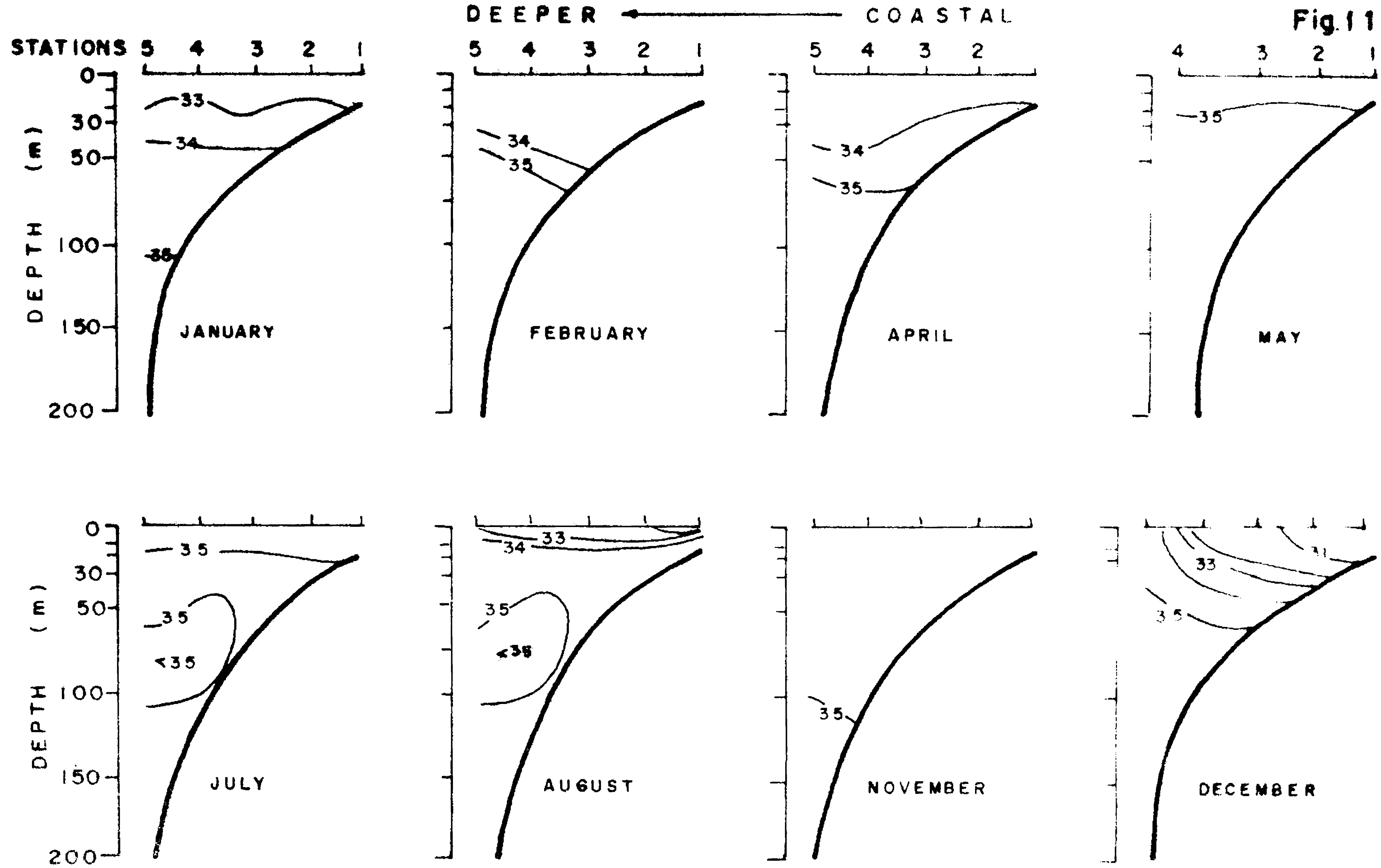

DEEPER ← COASTAL
STATIONS 5 4 3 2 1
DEPTH (m)
0
30
50
100
150
200
JANUARY
FEBRUARY
APRIL
MAY
JULY
AUGUST
NOVEMBER
DECEMBER
33
34
35
<35

Fig. 11

where the salinity values were found to be 33.50‰, the salinity were all above 35.00‰ within the shelf in the month of November. During December the upper layers contained lower salinity water probably due to the spreading of river run off as observed from the salinity distribution pattern.

Density (Fig.12):

The sigma-t values within the upper 20 metre layer ranged between 20.63 - 21.00. Comparatively low density water was observed at surface layers near to the coast. Density showed increase at all depths in the month of February. Again by April, lower values were observed at surface layers, while below 75 metres the density continued to increase. The increasing trend of density continued till August with the isopycnals showing gradual vertical ascent as observed from the density distribution pattern for April-August period. During August comparatively denser water was observed near to the coast. The sigma-t value near to the coast was 23.60 and in the entire column below 20 metre depth the sigma-t values were above 24.00. From the density distribution pattern of November, it was observed that the sigma-t values at all depths decreased considerably and the 24.00 isopycnal moved below to a depth of 50 metres. By December the

FIGURE 12

Vertical sections of density off Cochin for different months (1974).

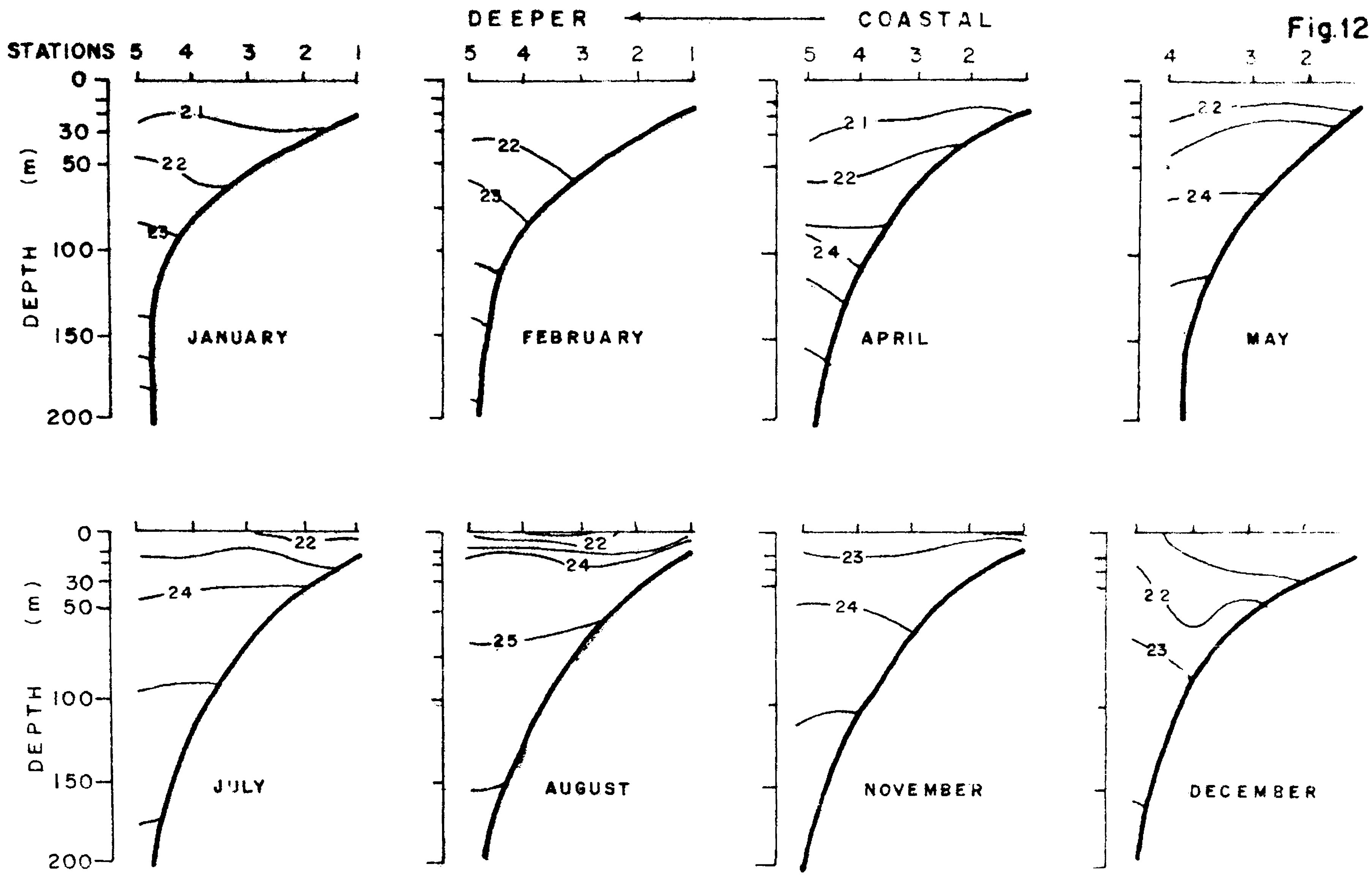

DEEPER
COASTAL
STATIONS
5 4 3 2 1
DEPTH (m)
0
30
50
100
150
200
21
22
23
24
25
JANUARY
FEBRUARY
APRIL
MAY
JULY
AUGUST
NOVEMBER
DECEMBER

Fig.12

isopycnals moved to deeper layers and density values considerably dropped down to values below 20.00 at the coastal stations. The comparatively lower values observed during December are due to the influence of very low salinity conditions prevailing in this area during December.

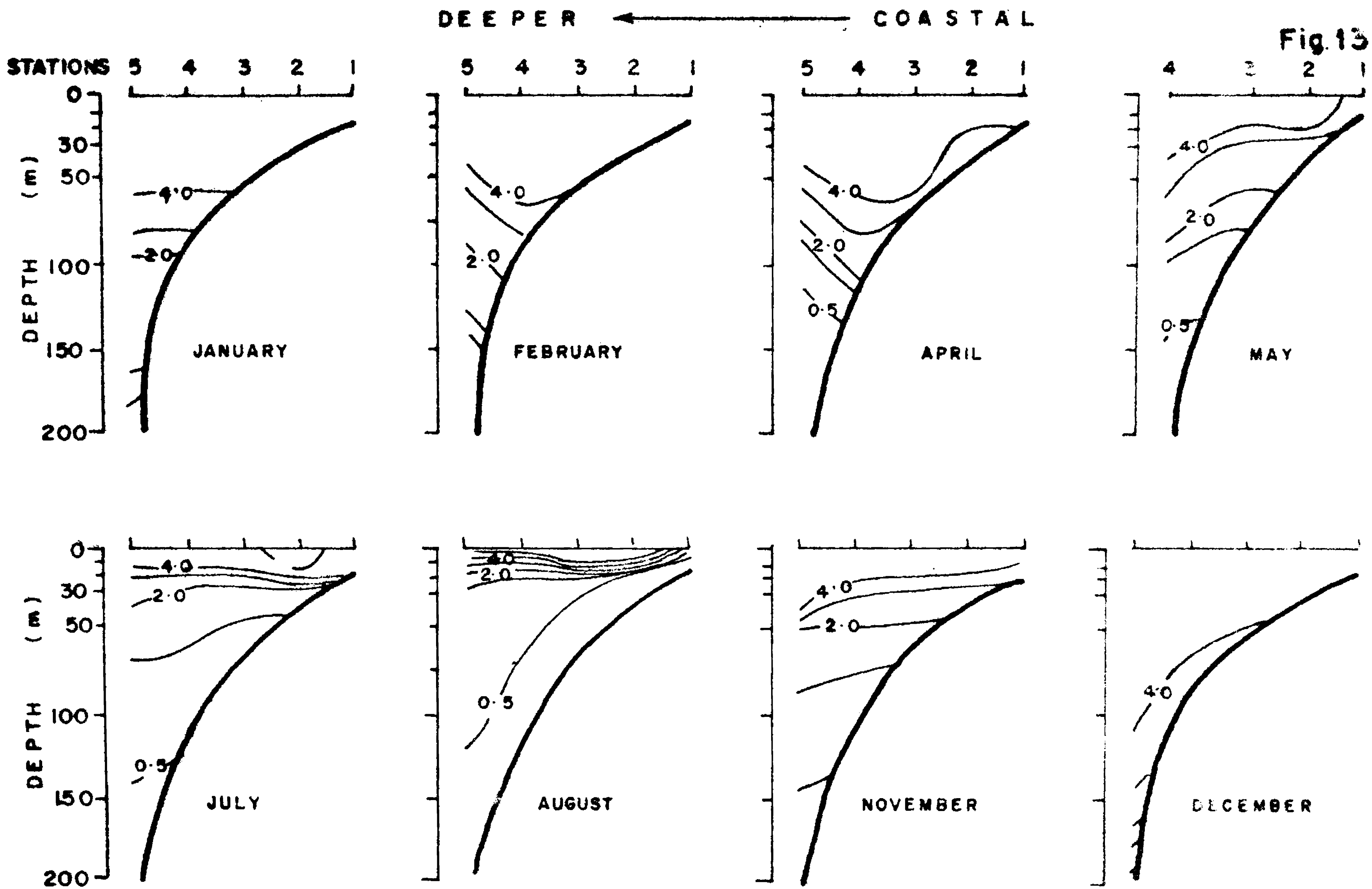
Dissolved oxygen (Fig.13):

The dissolved oxygen content in the upper 50 metre depth layer within the shelf were all above 4.00 ml/L in the month of January. There was not much variation in the oxygen distribution pattern of the upper 100 metre layer within the shelf during January-April period except for the gradual upslope observed to the 0.5 ml O_2/L layer from a depth of about 175 metres to about 125 metres during this period. By May, the upward movement of the low oxygenated deeper waters further intensified and at stations close to the coast, values below 4.00 ml/L were observed. The values at subsurface levels also decreased considerably during this period. By July, at upper layers upto the middle of the shelf, the oxygen values were found to be above 5 ml/L and the subsurface values continued to decrease in July. By August, the dissolved oxygen values within the entire shelf dropped considerably and values below 1.00 ml/L were observed at all subsurface layers within the upper 10 metre level. The surface values within

FIGURE 13

Vertical sections of dissolved oxygen off Cochin for different months (1974).

Fig.13


DEEPER ← COASTAL
STATIONS
DEPTH (m)
JANUARY
FEBRUARY
APRIL
MAY
JULY
AUGUST
NOVEMBER
DECEMBER
4·0
2·0
0·5

the shelf were all above 5 ml/L, while at surface near to the coast, only 3.77 ml/L were recorded. By November, the higher values observed at the surface layers, as well as the influence of low oxygenated water at subsurface layers, disappeared with the deepening of the isolines. The 0.5 ml/L oxygen layer which covered the entire bottom of the shelf during August moved to a depth of 150 metres in November. The low oxygenated layer moved to further deeper depths in the month of December and comparatively well aerated water of above 4 ml O_2/L covered the entire shelf.

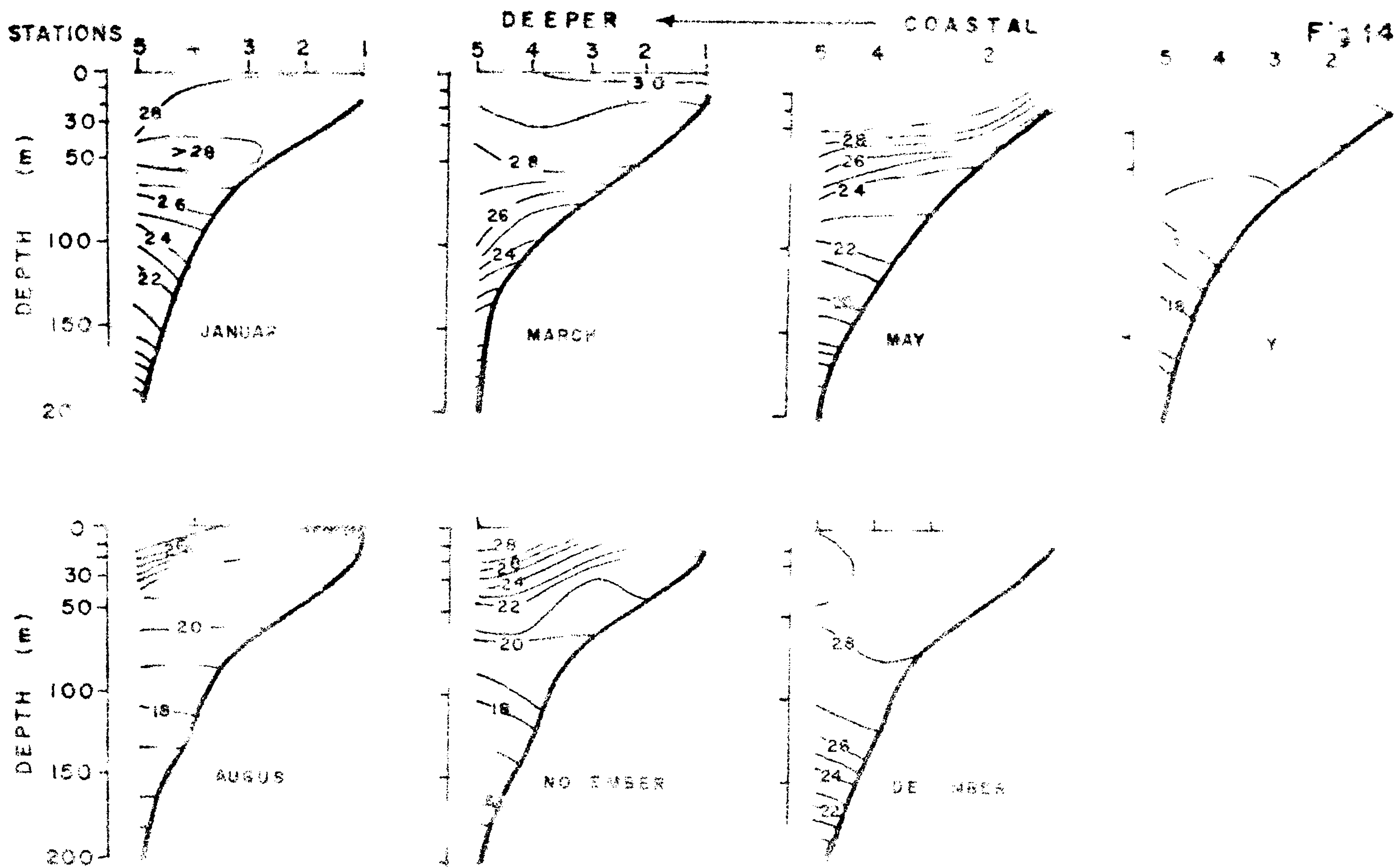
3.4 Off Kasaragod

Temperature (Fig.14):

Temperature at surface layers varied between 28.00 - 28.50°C during January. Higher temperature pockets (28.00 - 28.58°C) were observed at around 40 - 60 metre depth during this period. Temperature showed increase in the upper layers upto a depth of 50 metres in March with the temperature values at surface ranging between 29.70 - 30.50°C. Comparatively warmer waters were observed near to the coast. By May, the temperature within the upper 30 metre layer showed decrease due to the effect of the upward tilting of the isotherms and as a result, temperature near to the coast also decreased considerably. The

FIGURE 14

Vertical sections of temperature off Kasaragod for different months (1974).



STATIONS
DEEPER
COASTAL
DEPTH (m)
JANUAR
MARCH
MAY
AUGUS
NO EMBER
DE MBER

Fig 14

decreasing trend of temperature continued in July and August. Temperature of the subsurface layers dropped down to 21.00 - 22.63°C in August. Temperature above 26.00°C were observed at surface only at deeper stations. Temperature at surface layers gradually increased and above 1-2°C increase in temperature was observed at all depths in the upper 50 metre depth layer in the month of November. While below this depth zone the temperature pattern remained almost same as that of August. The increasing trend of temperature continued and by December the temperature in the upper 50 metre depth layer were all above 28.00°C. The 26°C isotherm which was observed at around 10 - 20 metre in August moved down to a depth of about 125 metres by December.

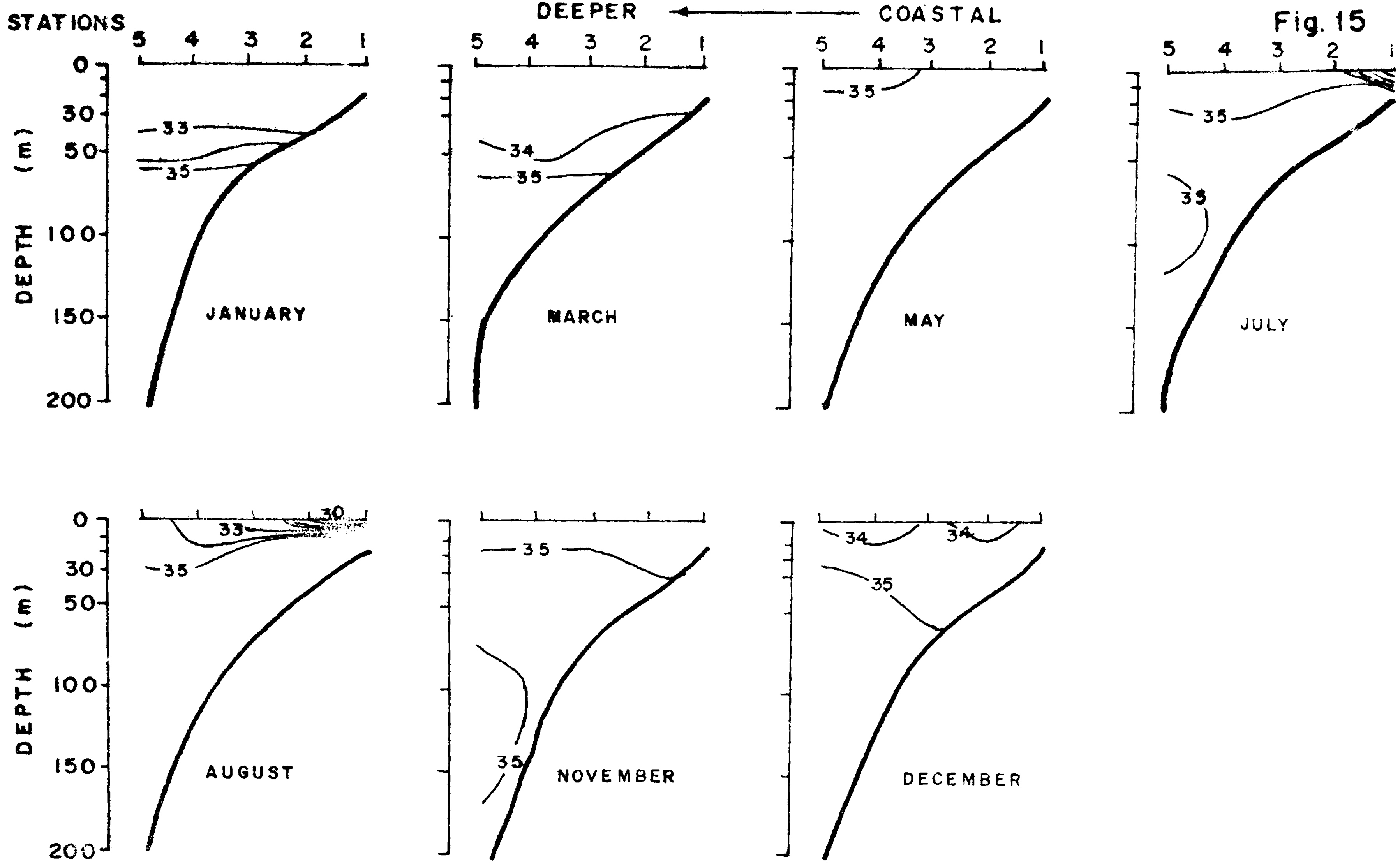
Salinity (Fig.15):

The salinity value in the upper 30 metre layer was found to be below 33.00‰ in the month of January. The salinity values showed gradual increase towards deeper layers. An increase in salinity of about 1.00‰ was observed in the upper 30 metre layer in March, while much variation in salinity was not observed below this depth zone during January-March period. The salinity values continued to increase in May also with salinity above 35.00‰ covering the entire shelf except for the surface

FIGURE 15

Vertical sections of salinity off Kasaragod for different months (1974).

Fig. 15


STATIONS
DEEPER
COASTAL
DEPTH (m)
JANUARY
MARCH
MAY
JULY
AUGUST
NOVEMBER
DECEMBER
33
34
35
30

layers in the deeper stations. In July very low salinity (values below 27.00‰) was observed near to the coast at surface. Though a slight decrease in salinity were observed in the upper 20 metre layer during July, in general higher salinity conditions prevailed within the shelf. The salinity values within the upper layers continued to decrease in August also due to the spreading of the lower salinity water observed near to the coast in July, while below 20 - 30 metres salinity remained unchanged from July to August. The influence of the lower salinity water observed during July-August period completely disappeared in November.

A slight decrease of salinity of about 0.50 - 1.00‰ was observed at surface layer in December, when the salinity values below 50 metres in deeper stations showed comparatively higher values ranging between 35.00 - 35.90‰.

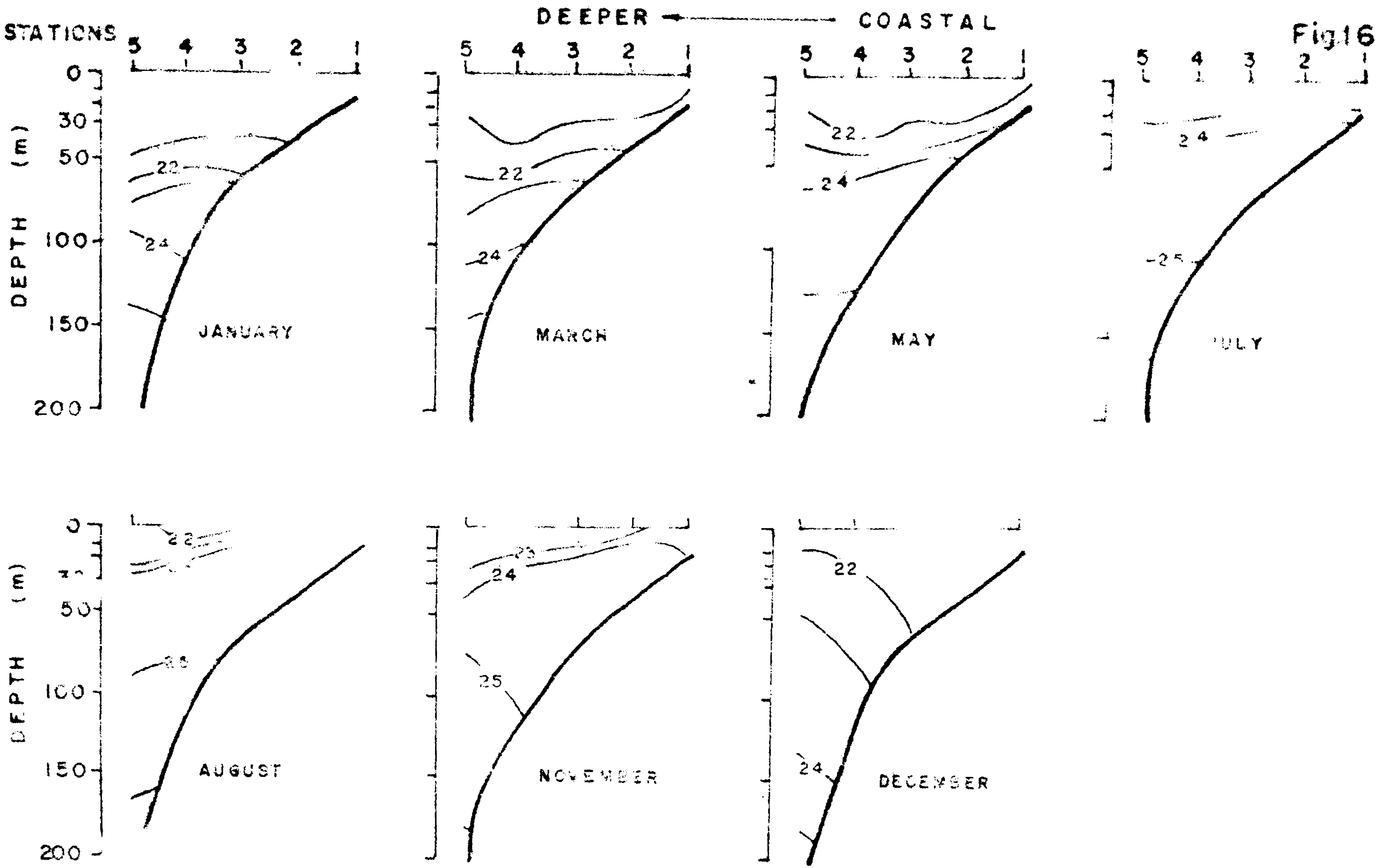
Density (Fig.16):

The sigma-t values in the upper 20 metre layer within the shelf varied between 20.20 - 20.70 in the month of January and within the shelf the values ranged between 20.29 - 25.73. The density distribution pattern for March indicated the penetration of higher density water from the deeper layers, thereby increasing the density of

FIGURE 16

Vertical sections of density off Kasaragod for different months (1974).

Fig.16


DEEPER ← → COASTAL
STATIONS
5 4 3 2 1
DEPTH (m)
0
30
50
100
150
200
22
24
25
JANUARY
MARCH
MAY
JULY
AUGUST
NOVEMBER
DECEMBER

the coastal waters. The density values continued to increase upto July with the upper 20 metre layer recroding values between 22.05 - 23.63 and by August higher density values above 24.00 were observed at 10 metre depth in the coastal stations. The density distribution continued to remain same in November also with slight increase in density at surface layers. By December the isopyonals moved to deeper layers indicating lower density conditions within the shelf with values ranging between 21.15 - 22.00 within the upper 50 metre depth layer.

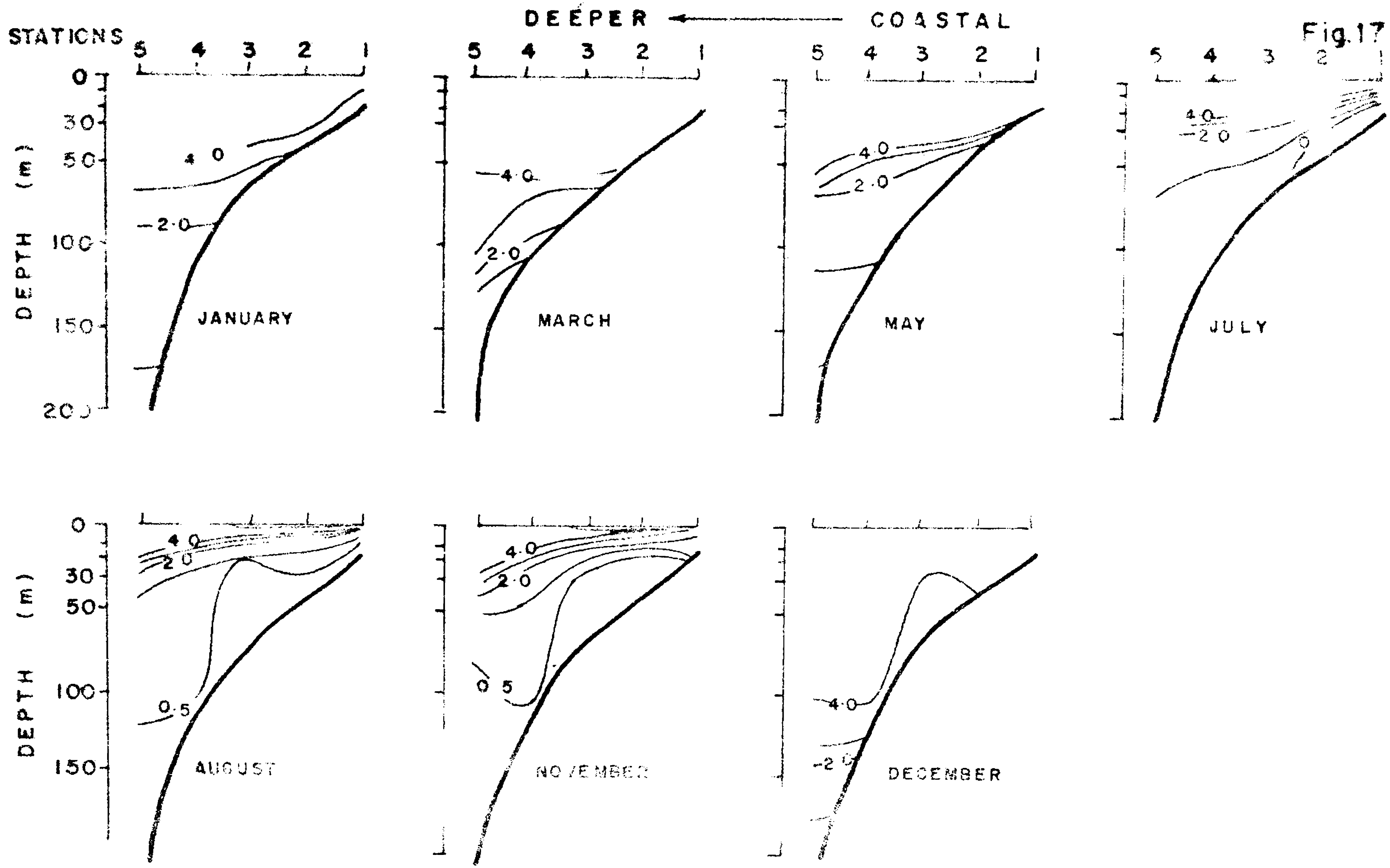
Dissolved oxygen (Fig.17):

The distribution of the dissolved oxygen content indicated the presence of well aerated water with values ranging between 3.60 - 4.53 ml/L within the upper 50 metre depth column during January-March period. An indication of the upward movement of the low oxygenated waters was observed at the deeper layers. The 1 ml O_2/L layer observed around 175 metresmoved to a depth of 125 metres during this period. The upward movement of the low oxygenated layer continued in May also and by July, low oxygenated water with values below 0.50 ml/L covered the entire bottom near to the coast. At 10 metre depth the dissolved oxygen content was found to be only 0.28 ml/L. The thickness of the well oxygenated layer increased towards deeper stations.

FIGURE 17

Vertical sections of dissolved oxygen off Kasaragod for different months (1974).

Fig.17



DEEPER ← COASTAL
STATIONS
DEPTH (m)
JANUARY
MARCH
MAY
JULY
AUGUST
DECEMBER

The distribution pattern remained the same in August also, but during this period the entire bottom of the shelf was covered with 0.5 ml O_2/L layer, as well as the surface values were all above 5 ml/L. The dissolved oxygen values showed considerable increase in the month of December with the deepening of the isolines and the disappearance of 0.5 ml O_2/L layer from the shelf waters within the shelf.

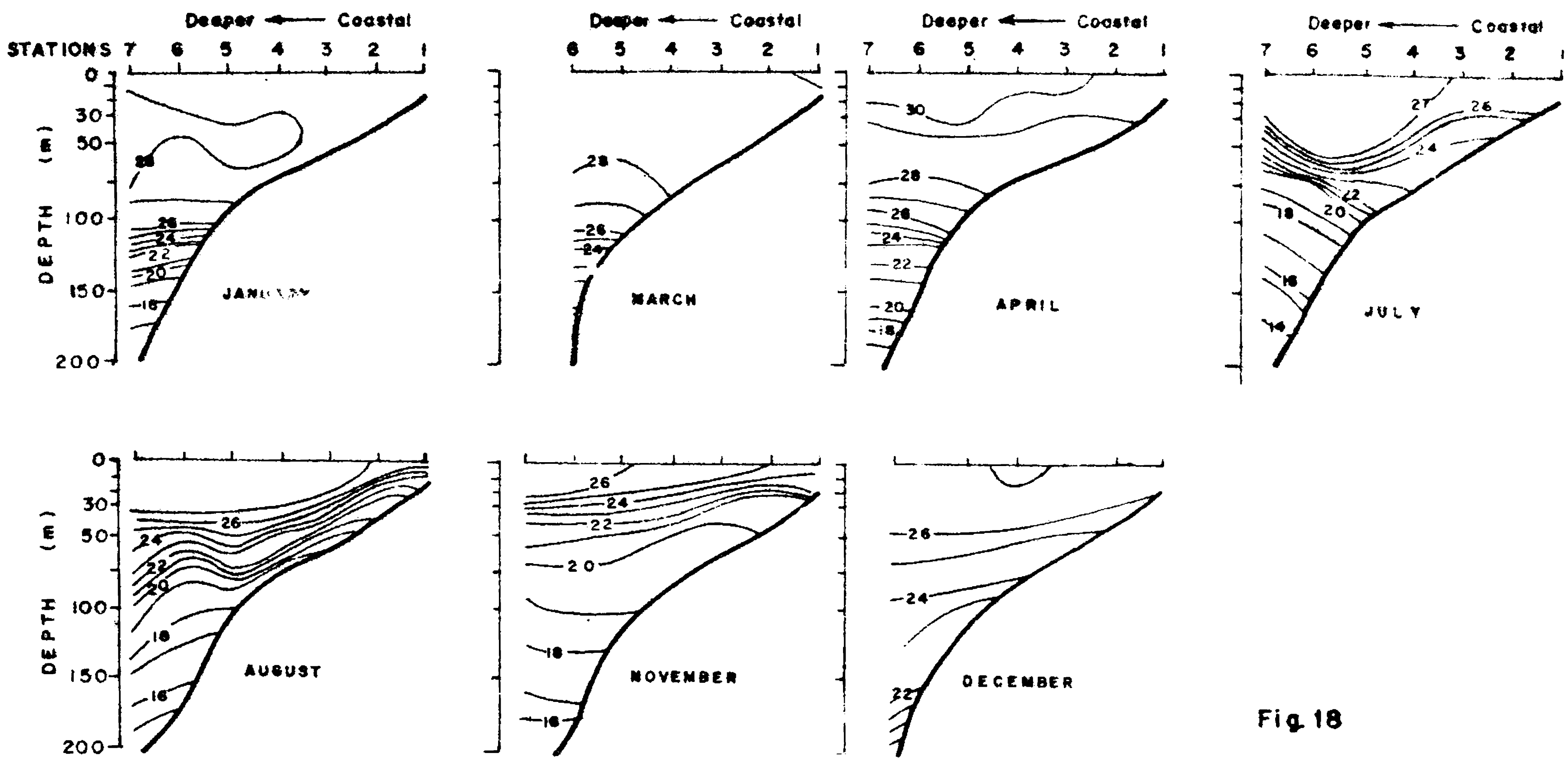
3.5 Off Karwar

Temperature (Fig.18):

In the month of January temperature distribution within the shelf showed the occurrence of higher temperature pockets at subsurface levels (20 - 75 metres) with temperature ranging between 28.00 - 28.75°C, while the surface values ranged between 27.60 - 28.00°C. The temperature showed gradual increase in March and by April the upper layer (10 - 20 metres) values were all above 30.00°C, except for the stations situated near to the coast, where the temperature was comparatively low. The temperature values at deeper layers (below 100 metres) showed slight decrease during this period. Considerable decrease in temperature values were observed in the month of July and the coastal stations recorded temperature values between 26.18 - 26.90°C. The temperature values

FIGURE 18

Vertical sections of temperature off Karwar for different months (1974).



Deeper ← Coastal
STATIONS 7 6 5 4 3 2 1
DEPTH (m)
0 30 50 100 150 200
JANUARY
MARCH
APRIL
JULY
AUGUST
NOVEMBER
DECEMBER

Fig. 18

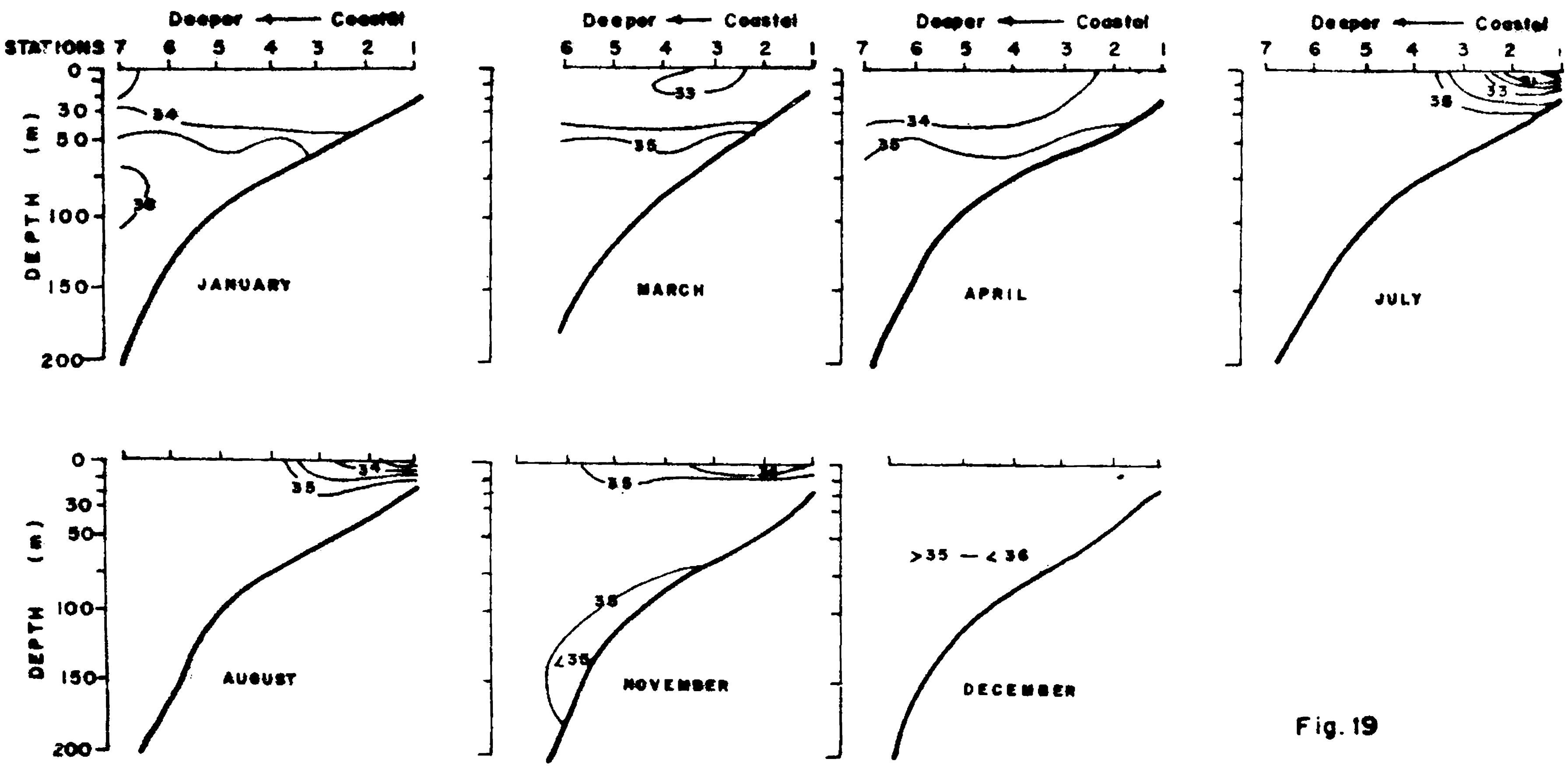
near to the coast showed decrease in August also. The temperature at surface near to the coast remained below 27.00°C. Temperature showed gradual increase towards offshore stations. Temperature decrease continued in November also with the coastal waters recording values below 25.00°C. The 24°C isotherm which was normally found around 125 metres in the month of January moved to a depth zone around 20 - 30 metres in November. But at surface, beyond the middle of the shelf a temperature increase of about 0.50°C was observed at all stations. The process of lowering of temperature from July to November is a characteristic feature observed in the section off Karwar. The temperature at all depths showed increase in December with the upper 50 metre layer temperature ranging between 26.00 and 27.40°C and the isotherms further moved down to deeper levels.

Salinity (Fig.19):

Salinity values within the upper 30 metre layer varied between 32.72 - 34.00‰. The salinity values showed gradual increase towards bottom with values above 36.00‰ observed within 75 - 100 metre depth near to the edge of the shelf in the month of January. Salinity values showed gradual increase in March and by April comparatively higher salinity water was observed near to the coast with values

FIGURE 19

Vertical sections of salinity off Karwar for different months (1974).



Deeper ← Coastal
STATIONS 7 6 5 4 3 2 1
DEPTH (m)
JANUARY
MARCH
APRIL
JULY
AUGUST
NOVEMBER
DECEMBER
>35 — <36

Fig. 19

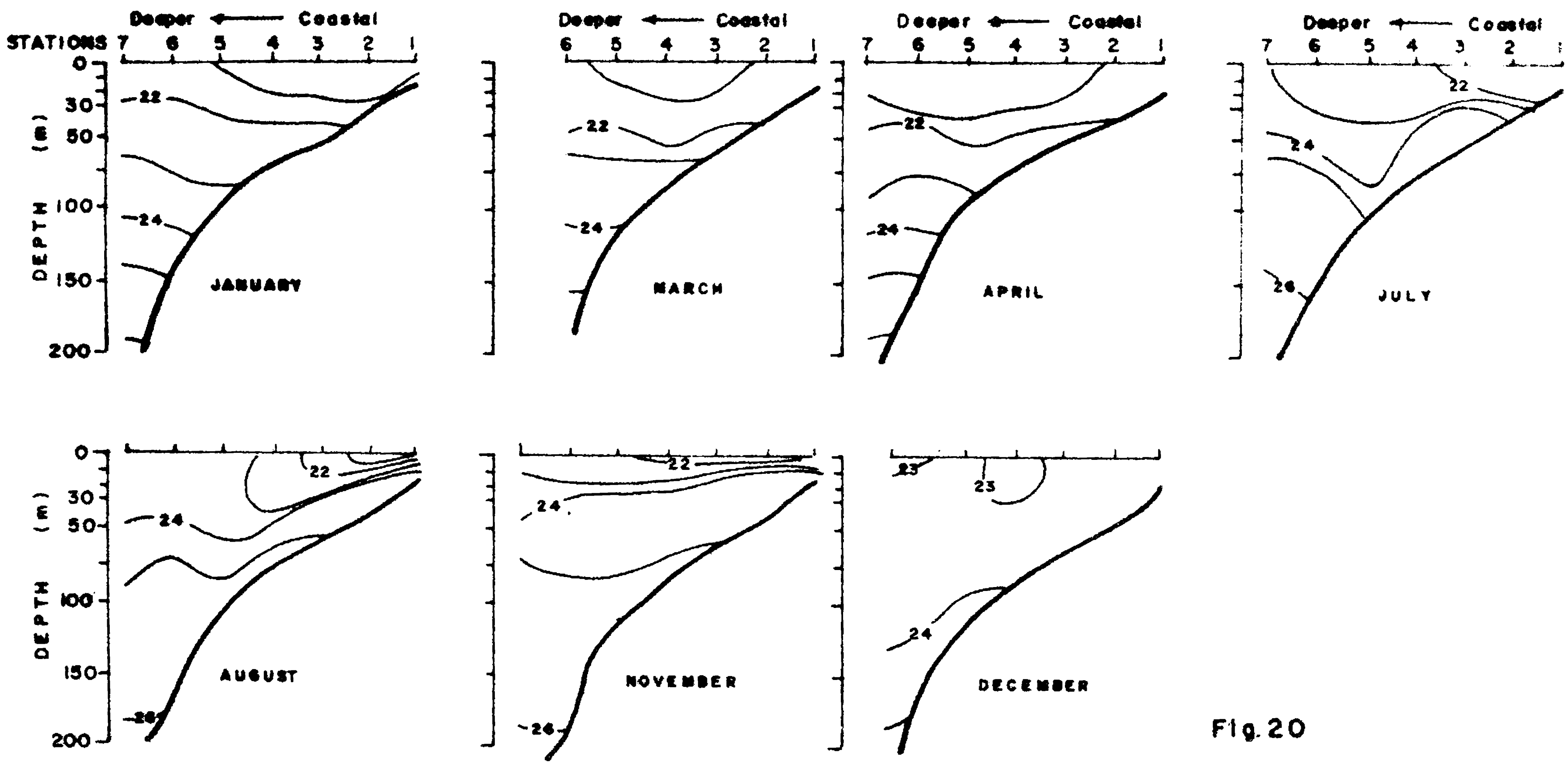
ranging between 34.23 - 35.18‰. By July, coastal waters became less saline and salinity values close to the coast were below 29.00‰ and the distribution indicated an outflow of less saline waters into the sea. Thus except for the upper layers close to the coast the entire column recorded comparatively higher salinity conditions (above 35.00‰) during this period. The salinity distribution within the shelf remained the same in August also. But slight increase in values were observed at all depths. The influence of the lower salinity water at surface layers disappeared by November and by December more or less uniform values of salinity ranging between 35.00 - 36.00‰ were observed at all depths.

Density (Fig.20):

The density values at surface layers within the coastal stations varied between 20.79 - 21.00 in the month of January. The distribution pattern indicated the presence of comparatively lighter water at surface layers in the middle of the shelf. The density values near to the coast showed slight increase in March. The upper 30 metre layer density decreased during March - April period but the density values near to the coast continued to increase. The isopycnals showed gradual ascent from April onwards and the density distribution pattern indi-

FIGURE 20

Vertical sections of density off Karwar for different months (1974).



Deeper ← Coastal
STATIONS 7 6 5 4 3 2 1
0
30
50
100
150
200
DEPTH (m)
22
24
26
23
JANUARY
MARCH
APRIL
JULY
AUGUST
NOVEMBER
DECEMBER

Fig. 20

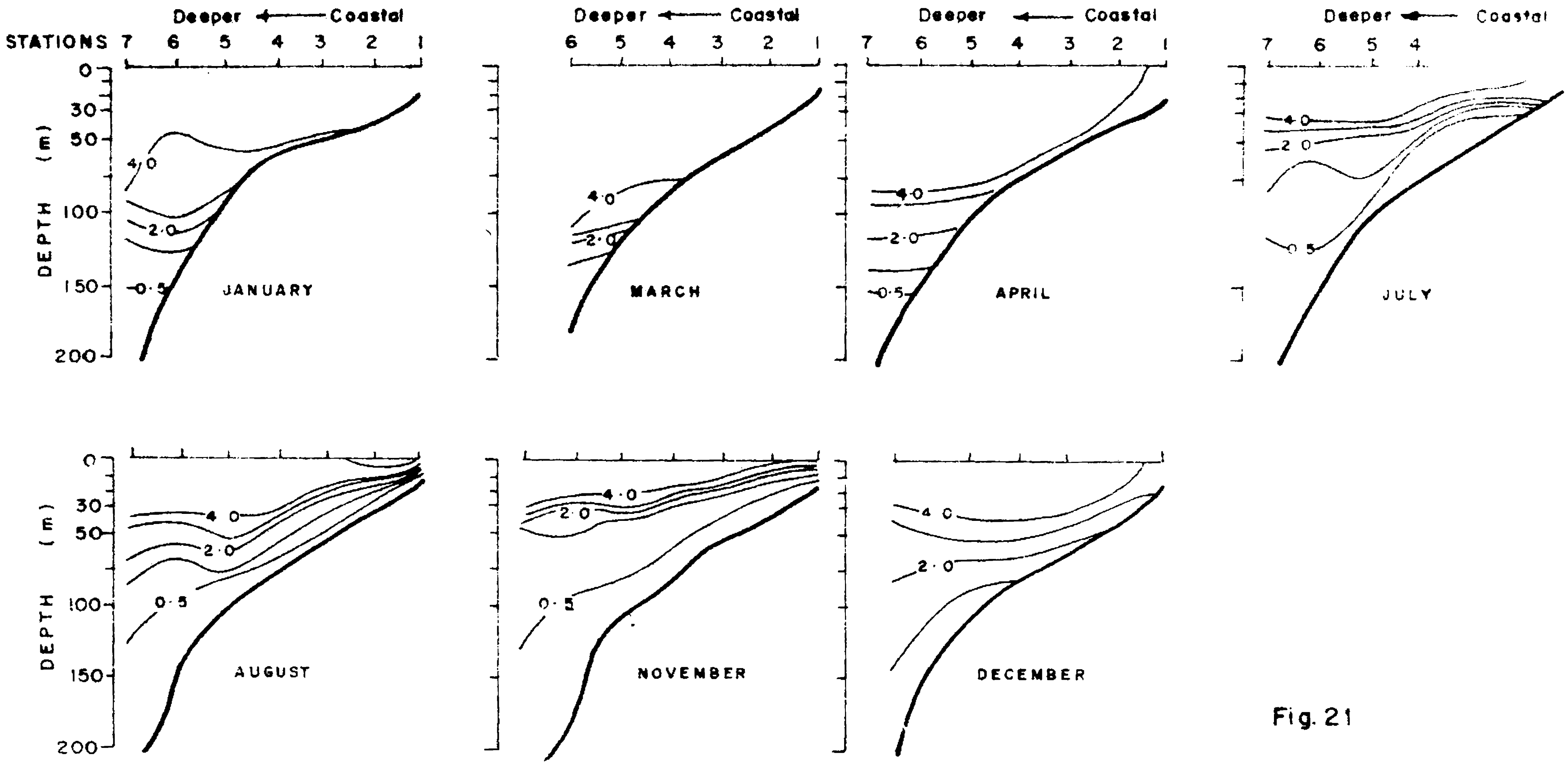
cated the presence of comparatively lighter water near to the coast in July - November period. In these months density values showed gradual decrease towards deeper stations. But the subsurface layers recorded higher density values even at shallow coastal stations during August - November period. In November the entire shelf water below 20 metres depth recorded sigma-t values above 24.00. Much variation in density was not observed below 150 metres during April - November period. Density varied between 23.00 - 24.00 in the month of December within the 125 metre depth layer. There was not much variation in density values between stations during this period. The 24.00 density isoline which observed at about 10 - 40 metre depth in the month of November within the shelf moved to a depth range of 100 - 125 metres by December within a period of 35 days.

Dissolved oxygen (Fig.21):

In the upper 50 metre layer dissolved oxygen values were above 4.00 ml/L in the month of January. 0.5 ml O_2/L layer was found at a depth of 150 metres. The 4.00 ml/L isoline moved down to a depth of 75 - 100 metres in March and the entire water column upto a depth of 75 metres was found to be well oxygenated in March - April period. By July, the low oxygenated deeper layers started penetrating

FIGURE 21

Vertical sections of dissolved oxygen off Karwar for different months (1974).



Deeper ← Coastal
STATIONS 7 6 5 4 3 2 1
DEPTH (m)
0
30
50
100
150
200
4.0
2.0
0.5
JANUARY
MARCH
APRIL
JULY
AUGUST
NOVEMBER
DECEMBER

Fig. 21

towards shore, reducing the oxygen values at the sub-surface layers near to the coast. The 0.5 ml O_2/L layer covered the bottom of the entire shelf in August and the thickness of the well oxygenated layer (above 4.00 ml/L) was limited to a depth zone of about 30 metres. The dissolved oxygen value was 0.31 ml/L at 10 metre depth near to the coast in August, while, at the same depth it was 0.40 ml/L in the month of November. The pattern of the dissolved oxygen distribution remained more or less similar in August-November period except for the higher values (5.00 ml/L) observed at surface in the coastal stations in August. The surface layers upto a depth of 30 metres were found well aerated in December with an increase in dissolved oxygen values at all depths within the shelf.

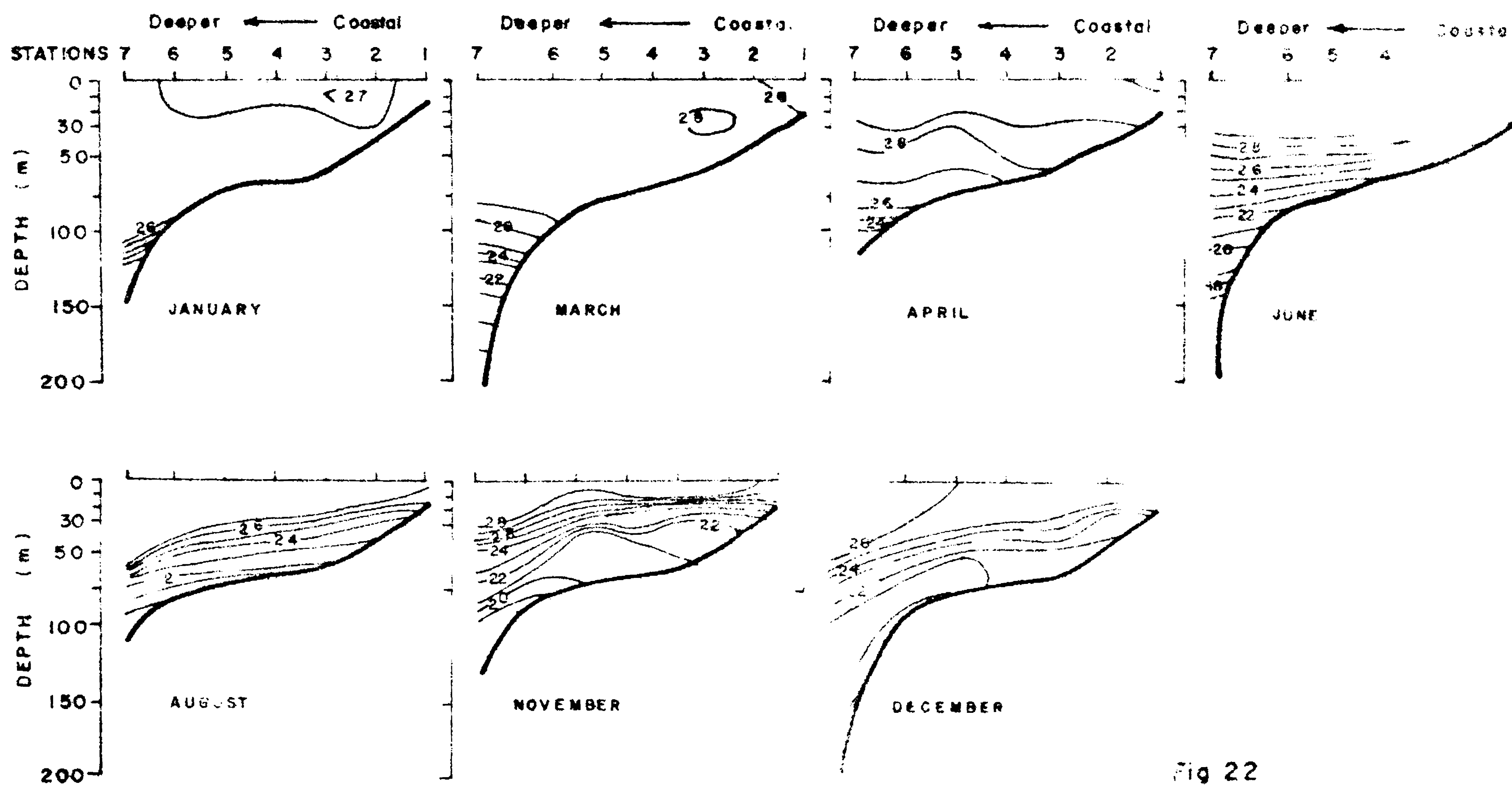
3.6 Off Ratnagiri

Temperature (Fig.22):

The temperature distribution within the shelf waters in the month of January indicated the presence of comparatively lower temperature water of 26.86 - 27.00°C in the upper 20 - 30 metre depth zone. The temperature values were all above 27.00°C below this depth zone upto a depth of 100 metres. The temperature showed considerable decrease below 100 metres and 22.00°C was observed at 125 metres depth.

FIGURE 22

Vertical sections of temperature off Ratnagiri for different months (1974).



Deeper ← Coastal
STATIONS 7 6 5 4 3 2 1
DEPTH (m)
0
30
50
100
150
200
JANUARY
MARCH
APRIL
JUNE
AUGUST
NOVEMBER
DECEMBER
< 27
28
26
24
22
20

Fig 22

By March, the temperature increased at all depths and the coastal stations recorded values above 28.00°C. Higher temperature pockets of temperature above 28.00°C was observed between 20 - 50 metre depth within the shelf. The isotherms showed gradual ascent during March. Temperature continued to increase in April and values above 30.00°C were observed at surface close to the coast. The isotherms continued to ascent in April also, and the upper 30 metre layer temperature within the shelf were all above 29.00°C in the month of June also. A temperature decrease was observed below this depth zone as indicated by the upslope of isotherms within the shelf. The upper 50 metre depth layer temperature dropped down to 26.30 - 27.80°C in the month of August and the 22° isotherm observed at around 125 metres in the month of January moved to a depth zone of 75 metres in August. The upper layer temperature showed increase in November, with the values ranging between 28.00 - 28.40°C in the 10 - 30 metre depth layer, while below this zone the decreasing trend of temperature continued in November also. By December the surface layer temperature further observed decreased to values below 26.00°C. Higher values were observed only towards deeper stations.

Salinity (Fig.23):

The salinity distribution pattern for the month of January indicated the presence of comparatively low salinity water near to the coast. Salinity values were below 35.00‰ at all depths near the coastal stations. In March an increase in values were observed at all depths seaward. Salinity values were above 36.00‰ below 75 metres. The low salinity water observed near to the coast in the month of January was found spreading towards the entire shelf upto a depth of 30 metre in March. The salinity distribution pattern was more or less similar to that of March in the month of April, except for the tongue like distribution of higher salinity (above 36.00‰) observed at a depth of 75 metres. This higher salinity water continued to spread towards the shallow coastal stations in the month of June as a result of salinity increased at all depths within the shelf. By August, lower salinity water (salinity below 34‰) was observed at surface near to the coast and salinity values above 36.00‰ continued to persist with 20 - 50 metres depth zone. Almost similar conditions prevailed in November also. But by December both the lower salinity (below 34.00‰) and the higher salinity observed near to the edge of the shelf, disappeared and the entire water column within the shelf recorded salinity values ranging between 35.00 - 35.69‰.

FIGURE 23

Vertical sections of salinity off Ratnagiri for different months (1974).

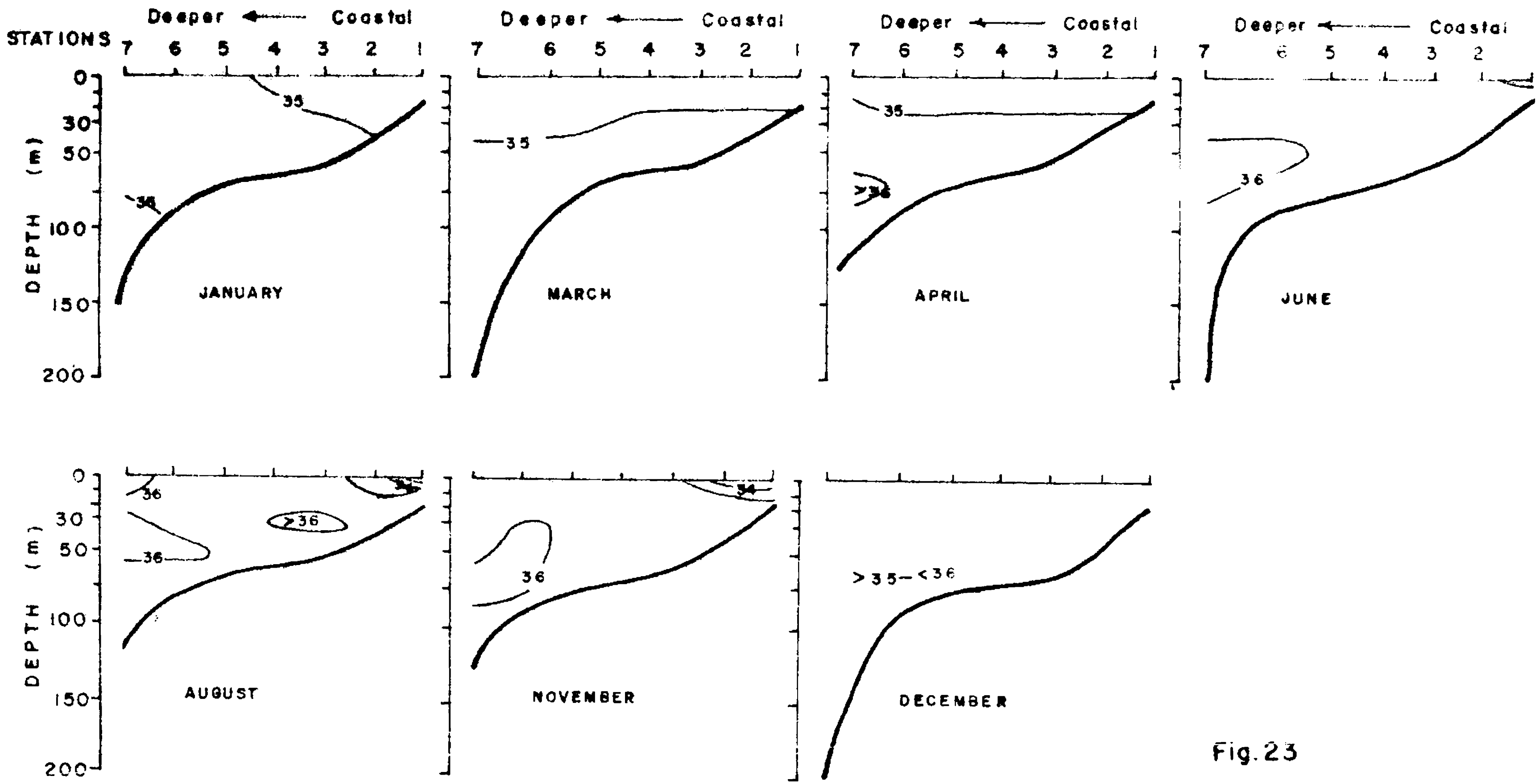

STATIONS
Deeper ← Coastal
7 6 5 4 3 2 1
DEPTH (m)
0
30
50
100
150
200
35
36
>36
34
>35–<36
JANUARY
MARCH
APRIL
JUNE
AUGUST
NOVEMBER
DECEMBER

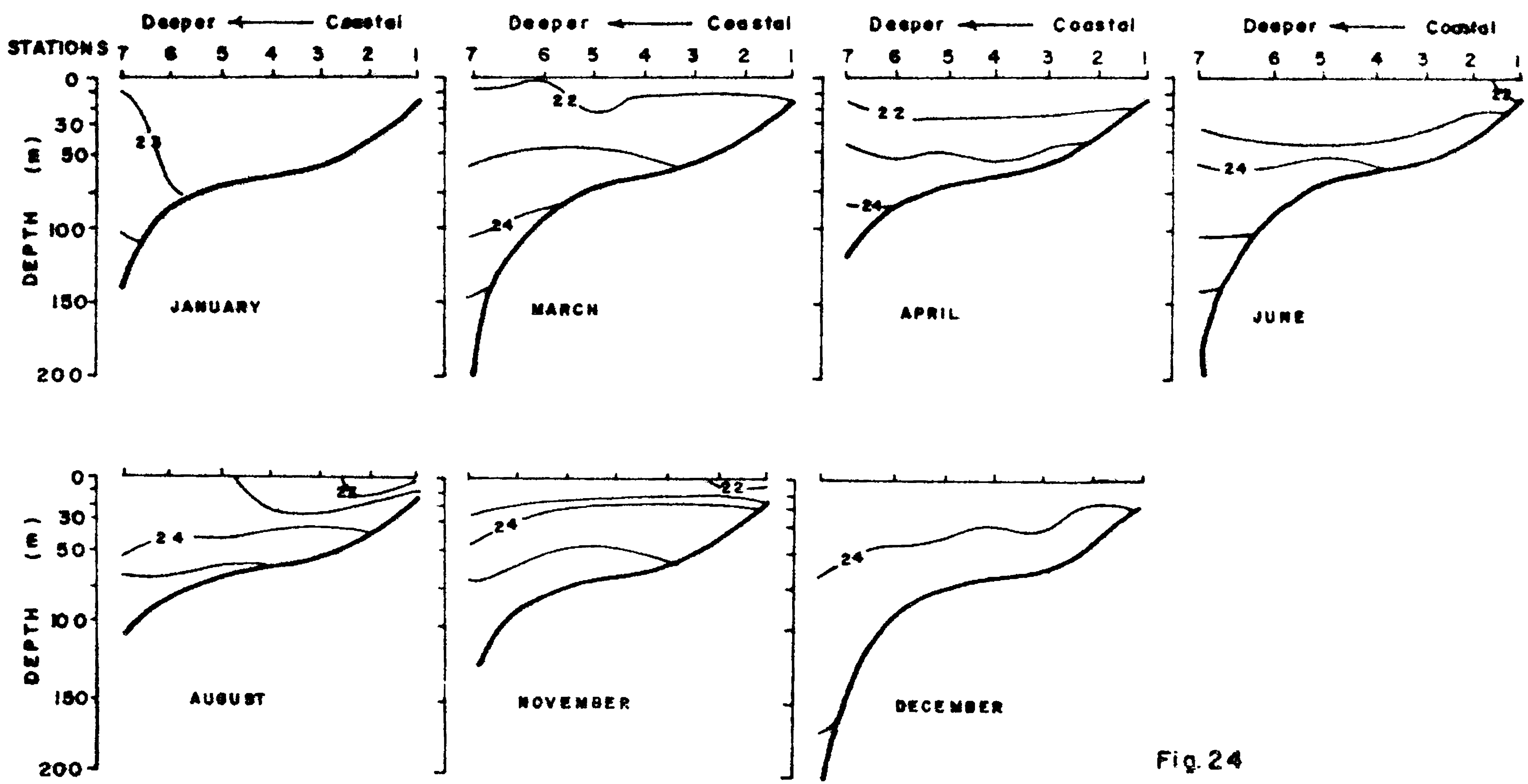
Fig.23

Density (Fig.24):

In the month of January the sigma-t values at all depths within the shelf waters were found to be above 22.17. Below 100 metre depth sigma-t values were found to be above 24.00. The density within the upper 10 - 20 metre layer were all below 22.00 in the month of March and the density did not show much variations below subsurface layers. The upper layer density continued to decrease in April also with the subsurface layers maintaining almost the same density conditions like the previous months. By June, the isopycnals moved further upward increasing the density at all depths and the surface values ranged between 21.60 - 22.35. Comparatively lighter water of density below 22.00 was observed near to the coast. In the month of August, except for the stations close to the coast sigma-t values were all above 23.00. The surface values of the deeper stations near to the edge of the shelf varied between 23.02 - 23.38. The subsurface layers below 20 metres continued to record higher density conditions (sigma-t values above 23.00) in the month of November and the denser water intrusion continued to persist towards the coast. In December the entire shelf recorded sigma-t values above 23.22 and the low density conditions observed at surface layers close to the coast in the preceeding months completely disappeared. Comparatively

FIGURE 24

Vertical sections of density off Ratnagiri for different months (1974).



Deeper ← Coastal
STATIONS
7 6 5 4 3 2 1
DEPTH (m)
0 30 50 100 150 200
JANUARY
MARCH
APRIL
JUNE
AUGUST
NOVEMBER
DECEMBER
22
24

Fig. 24

higher density water was observed in the section off Ratnagiri during December.

Dissolved oxygen (Fig.25):

In January the entire water column upto a depth of 75 metres were found well aerated with dissolved oxygen values above 4 ml/L. Decrease in oxygen values at bottom layers were observed in the coastal stations in March. Except for the bottom layers, where the dissolved oxygen values were below 3.00 ml/L, the entire column within the shelf contained well aerated water. The pattern remained more or less same in the month of April but by June upslope of poorly oxygenated layer of water towards the coast was observed. The thickness of the well aerated upper layer continued to decrease and by August, the entire bottom within the shelf was found covered with low oxygenated water of values below 1.25 ml O_2/L. Only a thin layer at surface extending to a depth of 10 - 30 metre within shelf was found well aerated in the month of November and the entire bottom was covered with water below 0.5 ml O_2/L. The vertical extent of the 4 ml O_2/L layer was limited to depths below 10 metres near to the coast. Dissolved oxygen values considerably decreased at all depths during this period. In the month of December, the dissolved oxygen values within the upper layers showed increase with 5 ml/L

FIGURE 25

Vertical sections of dissolved oxygen off Ratnagiri for different months (1974).

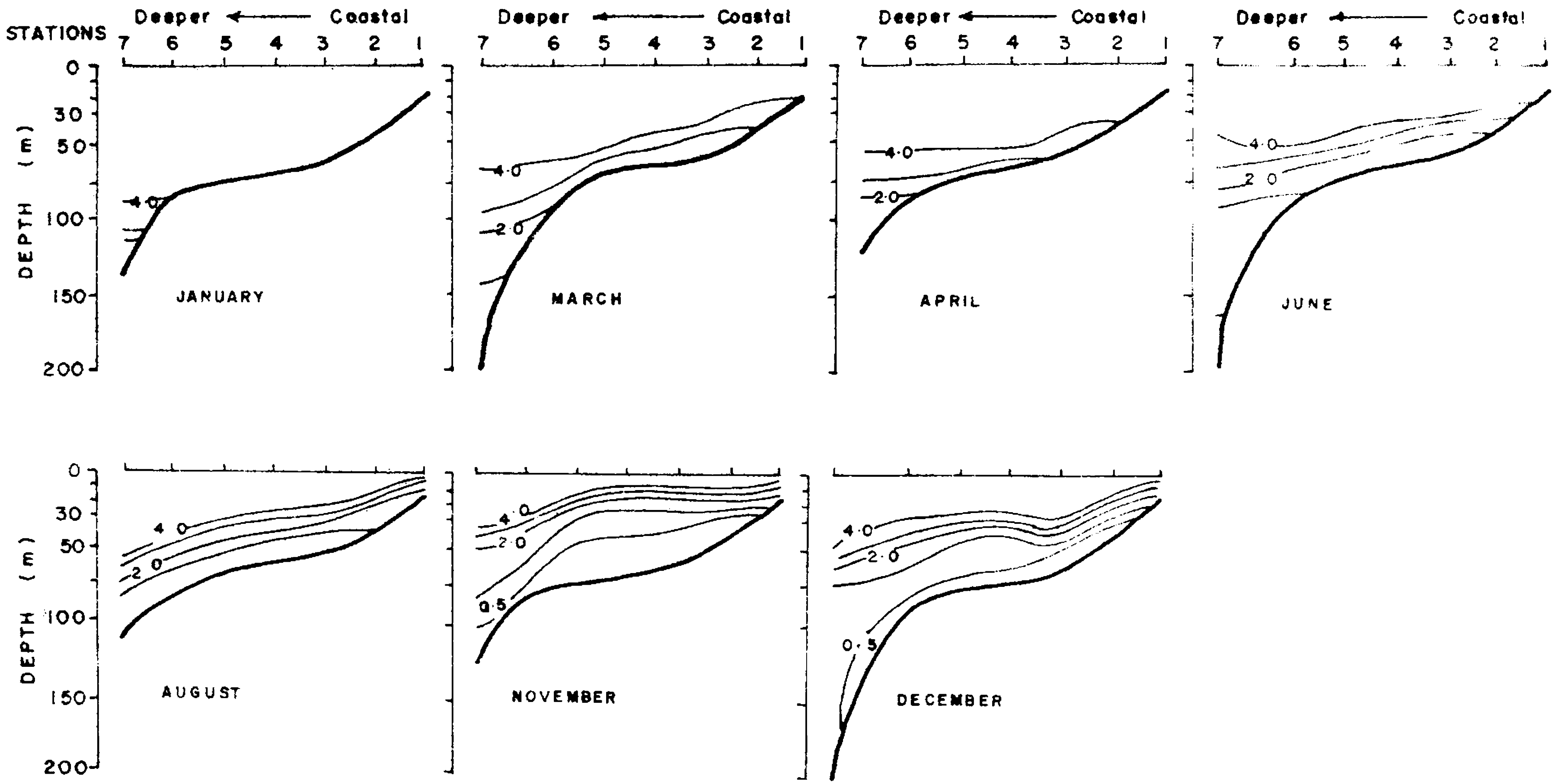

STATIONS
Deeper
Coastal
DEPTH (m)
JANUARY
MARCH
APRIL
JUNE
AUGUST
NOVEMBER
DECEMBER

Fig 25

layer at surface layers in the middle of the shelf.
The general distribution of the dissolved oxygen was more or less same as that of November.

CHAPTER 4

4 SEASONAL VARIATIONS OF THE HYDROLOGICAL PROPERTIES

Seasonal variations of temperature, salinity and dissolved oxygen within the shelf waters, upto 50 metre depth and their regional variations are studied. The seasonal mean value for each station was obtained from the average value of the parameter by clubbing the monthly values of the same for each season, separately for the 1972-75 period. For this purpose data of the core months in each season are chosen, thus April and May representing the hot weather season, July and August, the south-west monsoon and December and January the north-east monsoon. The seasonal and regional variations are discussed (Figs.26-31).

4.1 Hot weather season

Temperature:

Temperature distribution within the shelf along the coast showed considerable latitudinal variations during the hot weather season. Comparatively lower values were recorded near to the coast with temperature gradually increasing at all depths towards offshore. More or less similar pattern of distribution was observed in the section off Quilon also. While off Cochin the lower temperature conditions were not observed near to the coast and instead more or less uniform temperature conditions (temperature ranging between 29.60° - 29.90°C) prevailed in the upper layers. The temperature distribution indicated gradual increase in temperature towards northern sections. In the upper 50 metre depth layer off Kasaragod, temperature varied between 29.80° - 30.30°C, while the temperature near to the coast was found to be 29.70°C. The corresponding ranges of temperature for the 50 metre depth layer were 27.40° - 29.00°C and 28.40 - 29.70°C for the Cape Comorin and Quilon sections respectively. The temperature condition in the Karwar-Ratnagiri region did not show similarities with those of the southern regions. In the upper 50 metre temperature ranged between 27.80° - 30.00°C in the Karwar region and 27.10° - 29.60°C in the Ratnagiri region. From the temperature distribution, it was observed that the coastal waters were colder than the offshore waters in the southern sections at the surface and the subsurface levels, but in the northern sections beyond Kasaragod, colder water penetration towards the shallow coastal waters were not observed.

Salinity:

The salinity condition within the shelf unlike temperature, did not show such variations. In general, higher salinity values were observed in the northern sections, but decreasing towards south. More or less uniform values were observed throughout the shelf at all sections except for Quilon and Cochin, where comparatively lower salinity conditions prevailed close to the coast. The vertical variations in salinity values were also not appreciable at any section during this period.

Salinity values within the shelf off Cape Comorin were found varying between 34.21 - 35.18‰. Salinity close to the coast was comparatively higher than the offshore stations. The corresponding value of salinity off Quilon ranged between 34.14 - 35.42‰. In general, higher salinity values were found off Cochin, where lowest value of the monsoon season 33.3‰ was recorded close to the coast.

Dissolved oxygen:

The surface waters all along the coast were found to be well aerated during this season, with dissolved oxygen values above 4.0 ml/L, observed at all stations. The near shore waters were found to be oxygen deficient especially at subsurface levels, with the values ranging between 3.0 - 4.0 ml/L. The oxygen concentration within the shelf waters all along the coast indicated the presence of comparatively higher values towards the northern (Kasaragod-Ratnagiri) regions. The vertical variation in the dissolved oxygen values tended to be minimum towards off shore stations. The well aerated upper layers were found to have vertical extent of 30 metre depth in most of the sections during this season.

4.2 South-west monsoon season

Temperature:

Considerable variations have been observed in the temperature structure within the shelf all along the coast in the south-west monsoon season as compared to the hot weather season. Temperature values were found decreasing very steeply at all depths with the coastal stations recording comparatively lower temperatures. The temperature distribution indicated gradual increase of temperature towards offshore stations.

Upper layers were comparatively warmer in the northern regions. The temperature values within the upper 20 metre layer for the Ratnagiri section varied between 27.00° - 28.00°C. The vertical variation in temperature was found to be maximum in the Quilon-Karwar region, while off Cape Comorin and Ratnagiri, such variations in the vertical plane was found to be comparatively low. Lowest values of temperature at 10 metre depth close to the coast were 24.50°C at Karwar, 23.10°C at Kasaragod, 23.50°C at Cochin and 24.40°C at Quilon. Temperature variations were not much pronounced in the upper 20 metre depth layer in the Cape Comorin, Ratnagiri sections. The stratification of layers were most prominent in the section off Cochin, while the maximum temperature gradient was observed in the sections off Kasaragod and Karwar.

Salinity:

Salinity values in the upper layers also showed considerably variations in the south-west monsoon season from that of the hot weather season. The surface values were very low near to the coast in all the sections off Cochin and northward, with salinity increasing towards deeper stations. The values ranged between 28.42 - 34.70‰ in the sections off Cochin and Kasaragod, while the corresponding range of values were 31.90 - 36.00‰ off Karwar and Ratnagiri, whereas more or less uniform values, ranging between 34.10 - 34.80‰ were recorded at surface in the sections off Cape Comorin and Quilon where no effect of fresh water influence was noticed. The salinity values gradually increased towards bottom and the maximum values were observed between 20 - 50 metre depth within the shelf in most of the sections. Salinity values showed gradual increase at all depths from Cochin and northwards. Thus the values below 20 m within the shelf ranged between 35.00 - 35.70‰ off Cochin, 35.10 -

35.60‰ off Kasaragod, 35.30 - 36.10‰ off Karwar and 35.60 - 36.30‰ off Ratnagiri. A notable characteristic of the salinity distribution in the upper layers north of Cochin in the south-west monsoon period as compared to the hot weather season was that the considerable decrease in salinity in all sections in the Cochin-Ratnagiri area, and comparatively higher salinity conditions prevailing at all subsurface levels within the shelf. The salinity conditions in the hot weather as well as south-west monsoon seasons were more or less same in the sections off Cape Comorin and Quilon.

Dissolved oxygen:

During the south-west monsoon period the oxygen concentration at surface layers remained high all along the coast, especially in the southern regions off Cochin and Quilon, where 5 ml O_2/L water was observed at surface. The subsurface values were found to be very low in the near shore areas in most of the sections and this was much pronounced in the Cochin - Karwar area where 1 ml O_2/L water was observed at 10 metre depth near to the coast during this period. The dissolved oxygen concentration remained comparatively high in the Cape Comorin section, where the vertical variations were also found to be minimum.

4.3 North-east monsoon season

Temperature:

During the north-east monsoon period, the variations in the water properties between sections were found to be minimum as compared to the other seasons. While the vertical temperature variations were maximum in the south-west monsoon period (off Cochin, Kasaragod and Karwar), they were found to be minimum in the north-east monsoon period. The temperature varied between 26.00°C and 27.60°C in the section off Cape Comorin and 27.80°C and 29.20°C off Quilon. The temperature gradually decreased towards the northern sections with the temperature range off Ratnagiri being 23.30° - 27.50°C within the shelf. The layers were almost isothermal and the temperature inversions were observed between 10 and 30 metre at all sections. An increase in temperature of about 1.60°C at 20 metre depth from that of the surface value was observed off Quilon. The depth of mixed layer extended upto 50 metre in the Cape Comorin-Kasaragod region, while this depth decreased with increase of latitude north of Kasaragod. The temperature at surface near to the coast was low (Cape Comorin 26.70°C, Karwar 27.70°C and Ratnagiri 26.20°C) and in general temperature showed increase towards off shore stations.

Salinity:

As compared to the highly varied conditions of salinity in the south-west monsoon season characterised by very low values at surface and higher values at subsurface levels with strong vertical gradient, the north-east monsoon features were more or less similar to that of hot weather season. However, the salinity values were low when compared to the hot weather season and maximum variations in salinity values were within 1/100th parts of thousand only within any consecutive depth zone. As in the hot weather season, salinity showed gradual decrease towards southern sections. But all the coastal stations recorded low salinity, except for Cape Comorin, where similar to the other two seasons, comparatively higher salinity was observed near to the coast.

Generally, very low values of salinity ranging between 33.20 and 35.20‰ prevailed within the shelf off Cape Comorin with comparatively lower values (33.30‰ near to the edge of shelf. The pattern of distribution was found to be much varied in the section off Quilon, where the salinity values at all depths were found to be within the range of 33.50 - 35.60‰. As in the other seasons, surface salinity recorded off Cochin showed lower value, close to the coast (32.20‰) progressively increasing seaward. More or less same conditions prevailed off Kasaragod also with slightly increased values of salinity at all depths. Karwar and Ratnagiri sections did not show any influence of the low salinity water within the shelf as like in the other sections and the salinity values were found to be ranging between 34.30 - 35.70‰.

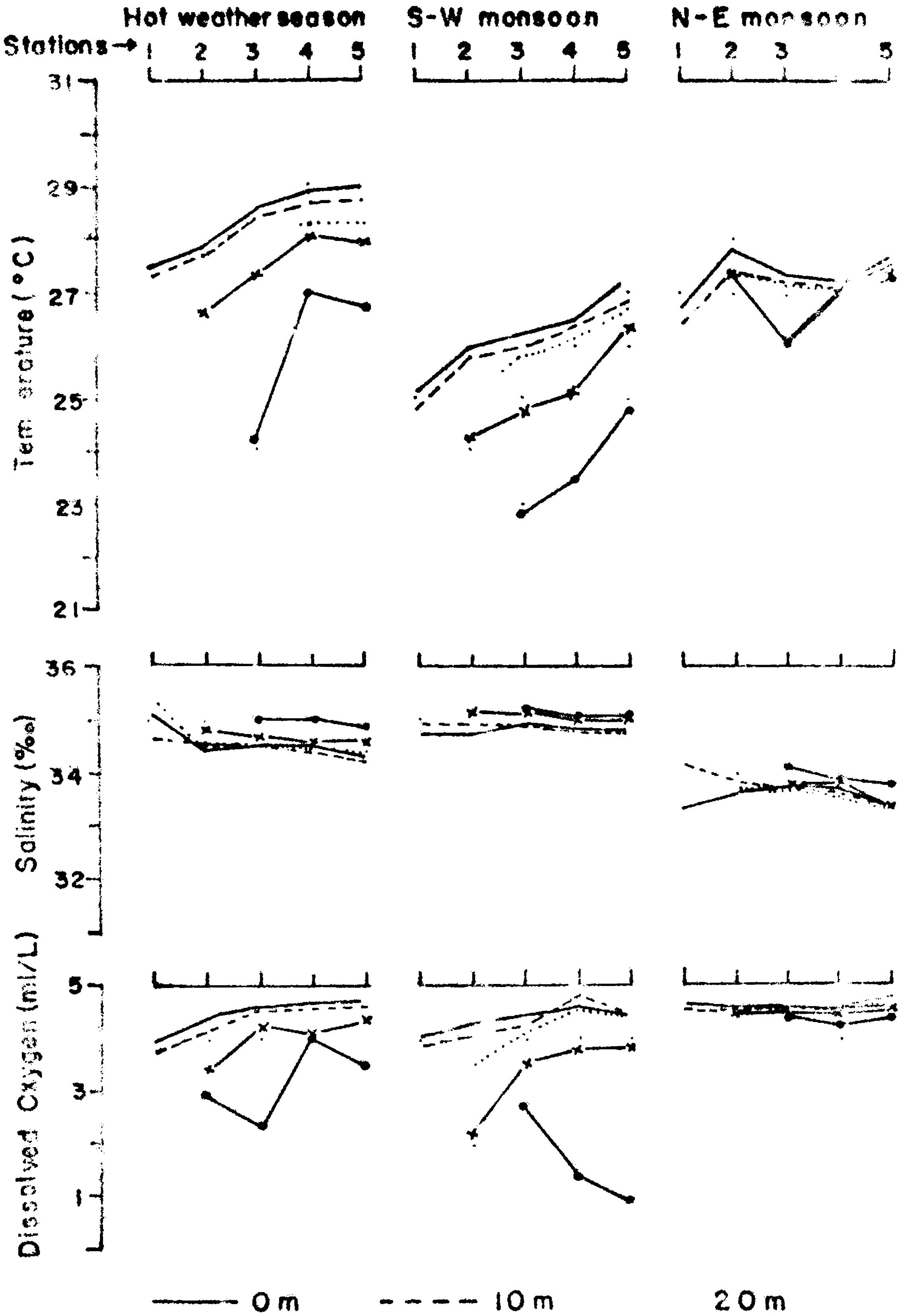
Dissolved oxygen:

As compared to the other two seasons, distribution of dissolved oxygen did not show much vertical variations during the north-east monsoon season. The upper 50 metre depth layer was found to be rich in dissolved oxygen with values ranging between 4.00 - 5.00 ml/L. But the sub-surface layers near to the coast was found to be comparatively less oxygenated in the northern most section off Ratnagiri during this period. Latitudinal variations in the dissolved oxygen values were also not appreciable during this season.

During the north-east monsoon season, temperature, salinity and dissolved oxygen did not show much variations as compared to other seasons. Temperature inversions were observed at surface layers dur to winter cooling. During this season except for the rather low temperature conditions observed off Cape Comorin, generally warmer waters were observed in the southern sections compared to the northern sections off Kasaragod and Ratnagiri. As regards salinity, higher values were observed towards north. The coastal waters were found to be less saline in the southern region. The upper layer within 50 metre were found well aerated all along the coast.

FIGURE 26

Seasonal distribution of temperature, salinity, dissolved oxygen off Cape Comorin.



Hot weather season
S-W monsoon
N-E monsoon
Stations →
Temperature (°C)
Salinity (‰)
Dissolved Oxygen (ml/L)
0 m
10 m
20 m
30 m
50 m

Fig. 26

FIGURE 27

Seasonal distribution of temperature, salinity, and dissolved oxygen off Quilon.

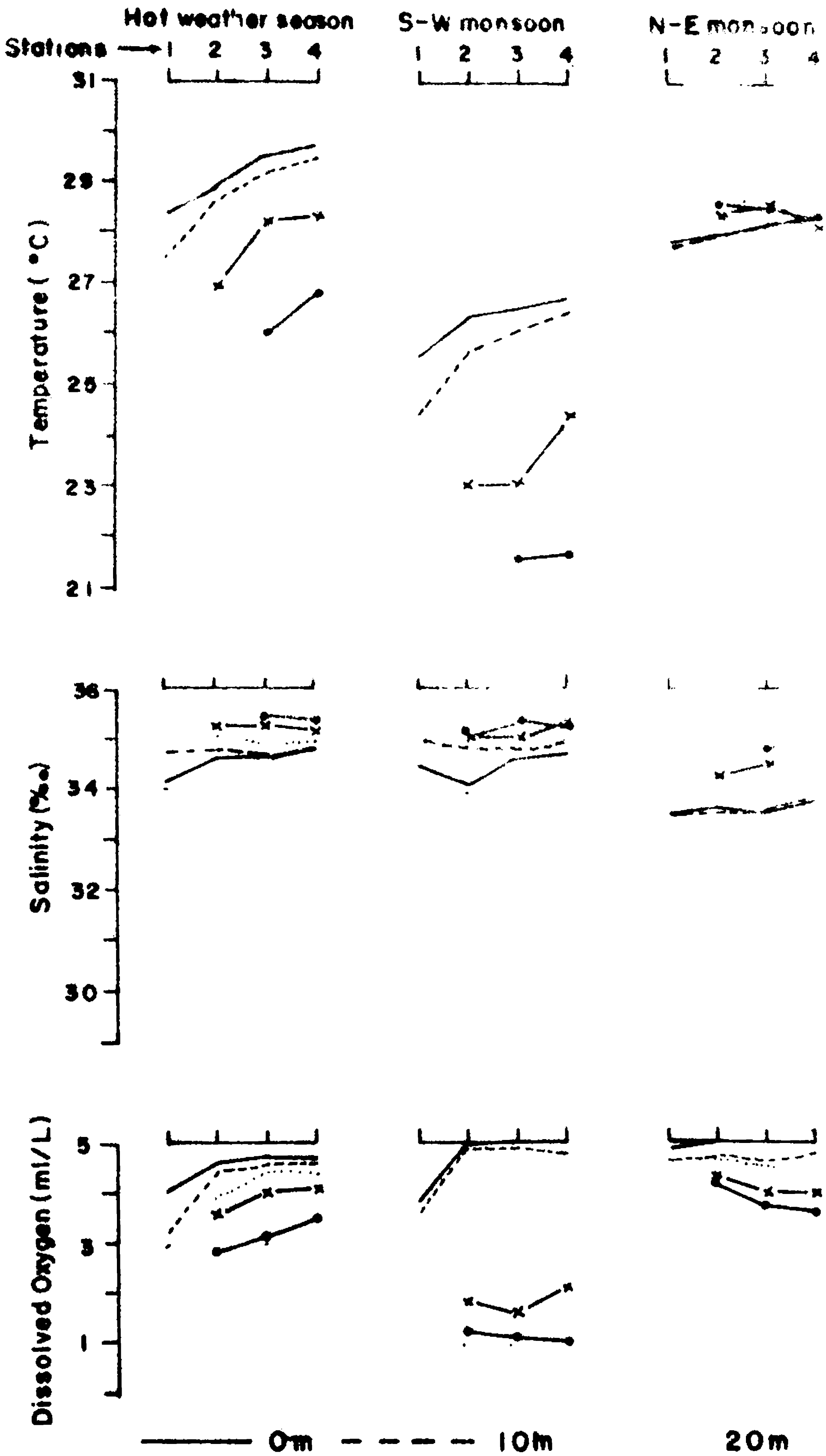
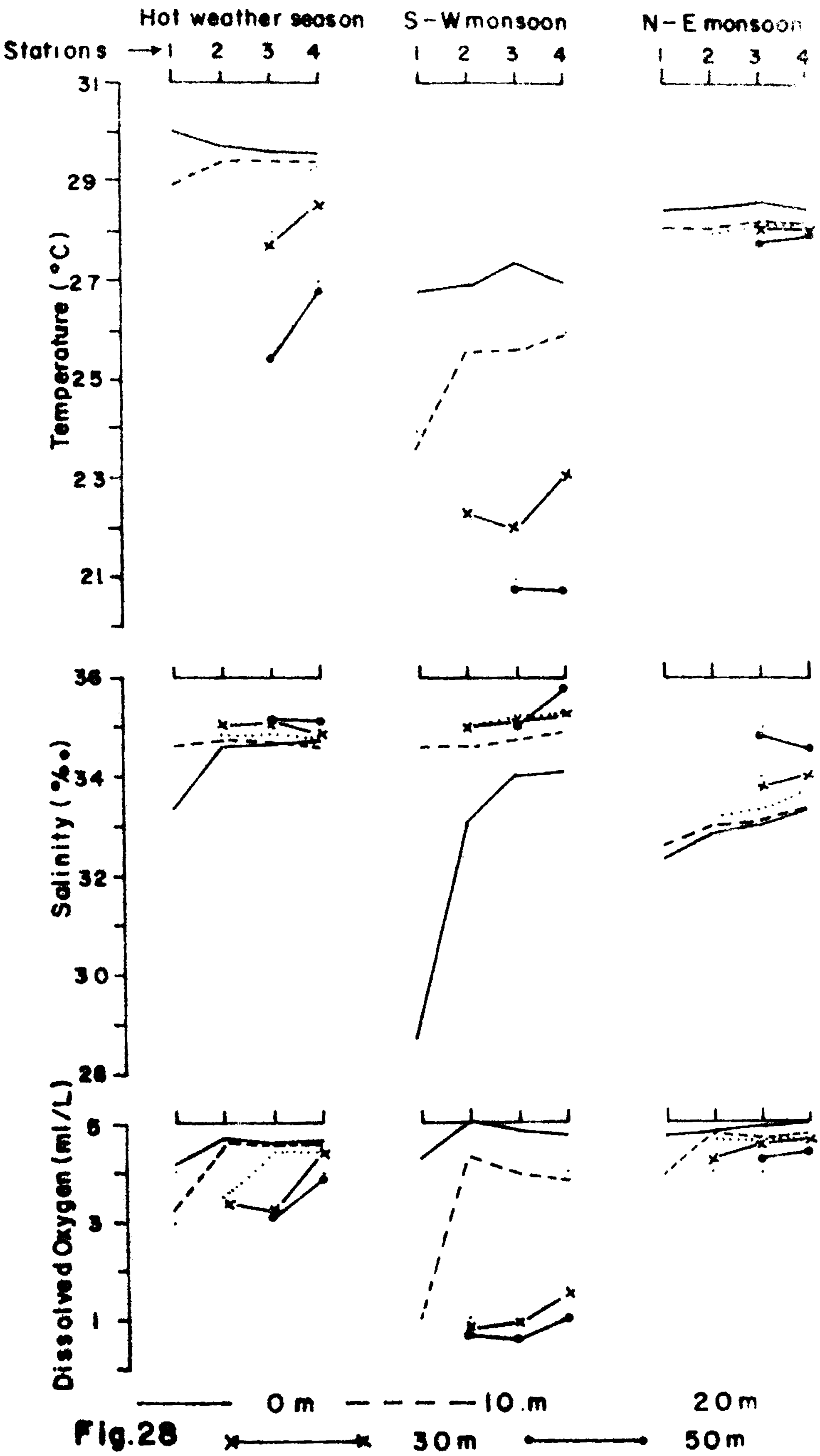

Hot weather season
S-W monsoon
N-E monsoon
Stations
1 2 3 4
31
29
27
25
23
21
Temperature (°C)
36
34
32
30
Salinity (‰)
5
3
1
Dissolved Oxygen (ml/L)
0m
10m
20m
30m
50m

Fig.27

FIGURE 28

Seasonal distribution of temperature, salinity and dissolved oxygen off Cochin.



Hot weather season
S-W monsoon
N-E monsoon
Stations → 1 2 3 4
31
29
27
25
23
21
Temperature (°C)
36
34
32
30
28
Salinity (‰)
5
3
1
Dissolved Oxygen (ml/L)
0 m
10 m
20 m
30 m
50 m

Fig.28

FIGURE 29

Seasonal distribution of temperature, salinity and dissolved oxygen off Kasaragod.

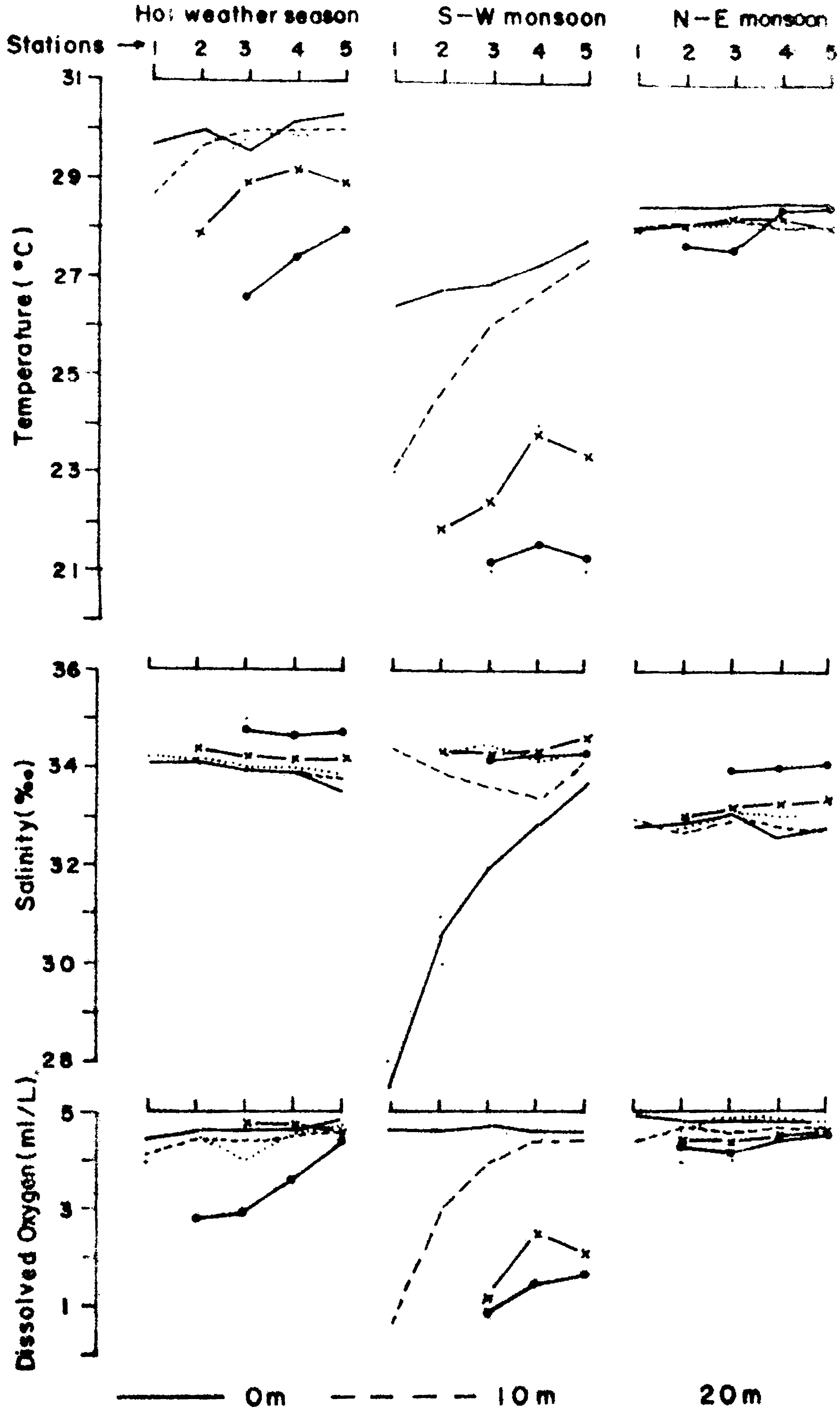
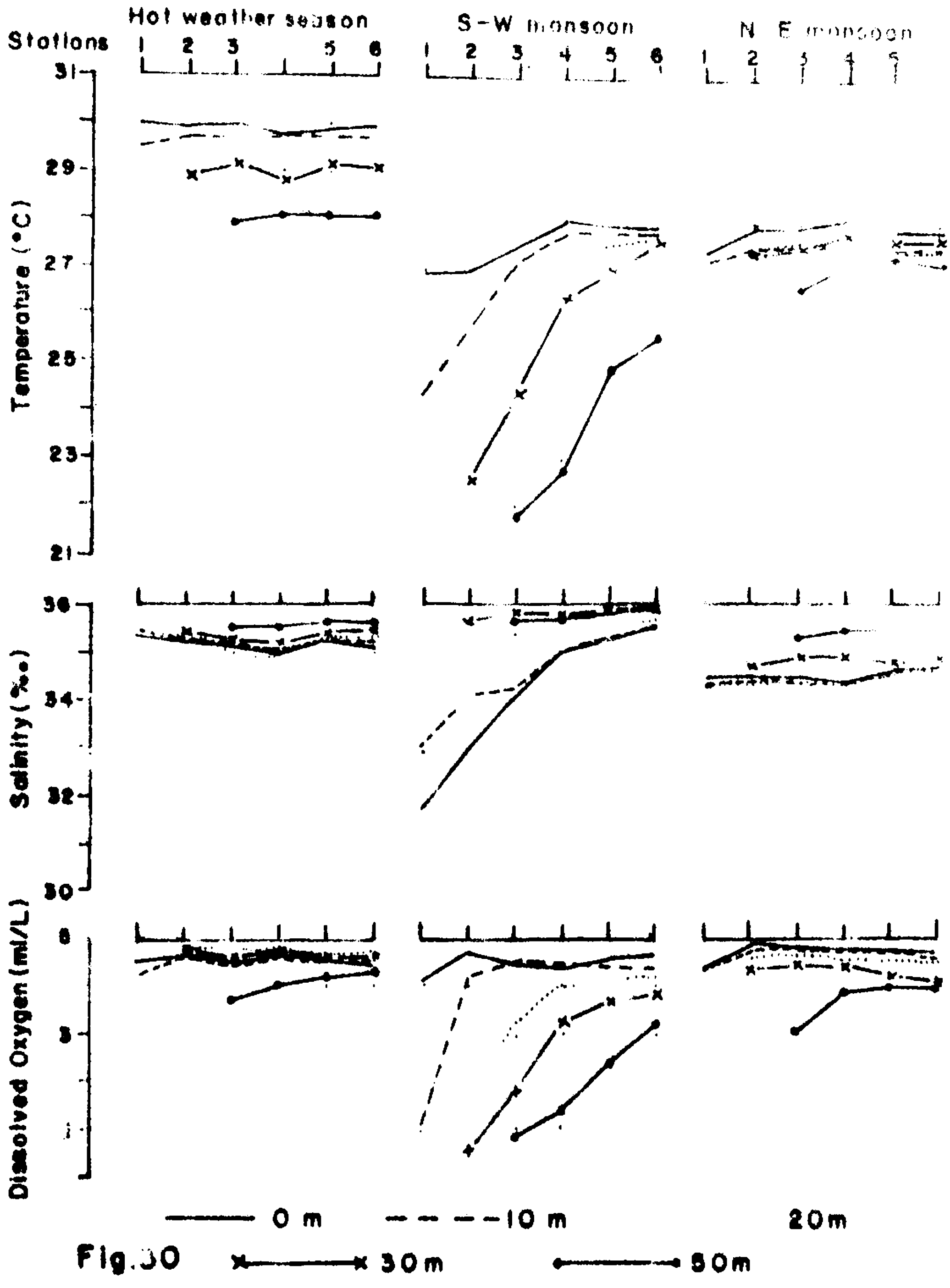

Hot weather season
S-W monsoon
N-E monsoon
Stations →
1 2 3 4 5
Temperature (°C)
31
29
27
25
23
21
Salinity (‰)
36
34
32
30
28
Dissolved Oxygen (ml/L)
5
3
1
0m
10m
20m
30m
50m

Fig.29

FIGURE 30

Seasonal distribution of tempeature, salinity and dissolved oxygen off Karwar.

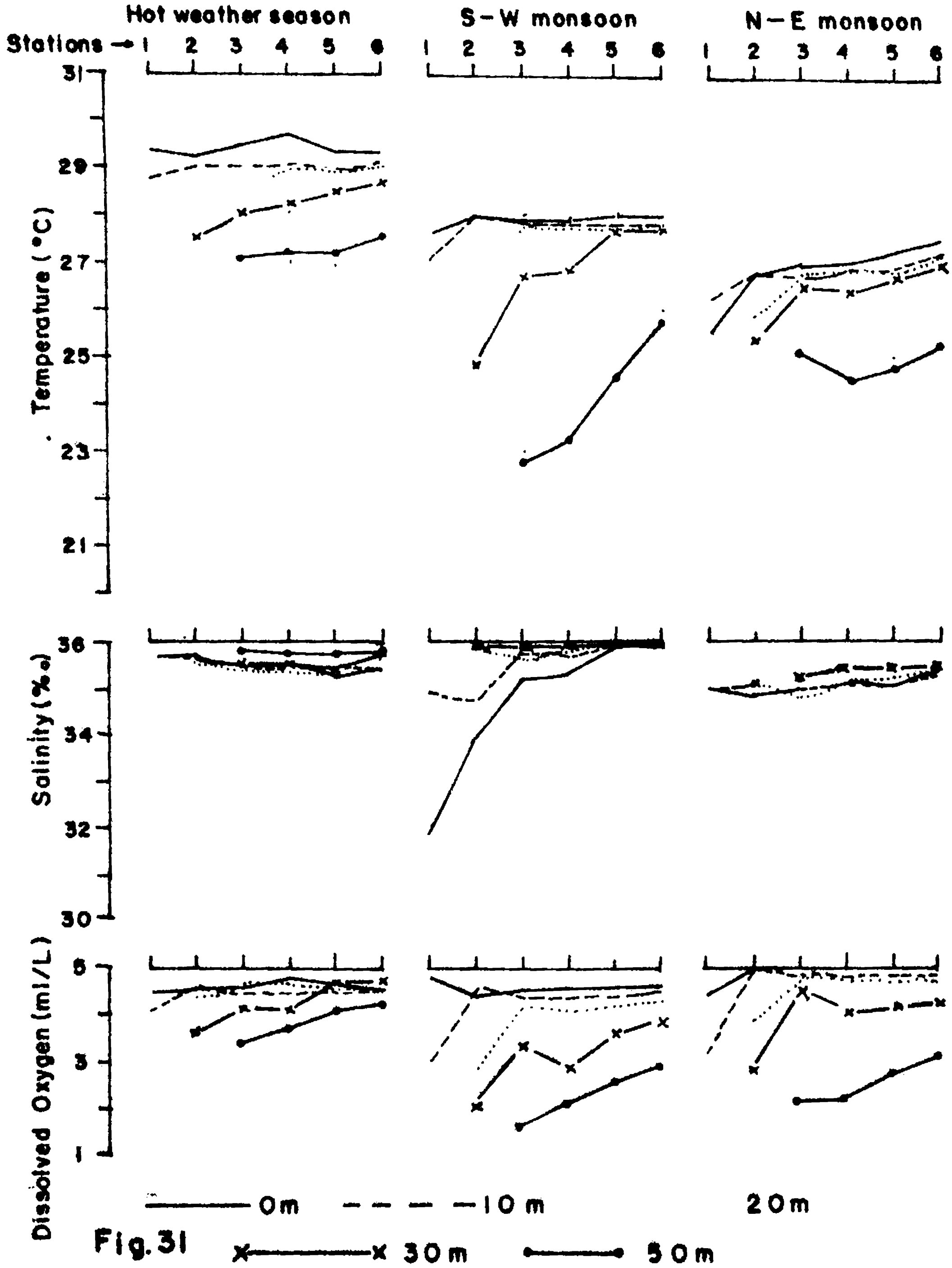


Hot weather season
S-W monsoon
N E monsoon
Stations
1 2 3 5 6
1 2 3 4 5 6
1 2 3 4 5
Temperature (°C)
31
29
27
25
23
21
Salinity (‰)
36
34
32
30
Dissolved Oxygen (ml/L)
5
3
1
0 m
10 m
20m
30m
50m

Fig.30

FIGURE 31

Seasonal distribution of temperature, salinity and dissolved oxygen off Ratnagiri.



Hot weather season
S-W monsoon
N-E monsoon
Stations → 1 2 3 4 5 6
Temperature (°C)
31
29
27
25
23
21
Salinity (‰)
36
34
32
30
Dissolved Oxygen (ml/L)
5
3
1
0m
10m
20m
30m
50m

Fig.31

CHAPTER 5

5 UPWELLING AND VERTICAL STABILITY OF THE SHELF WATERS OF THE WEST COAST OF INDIA

5.1 Upwelling

Upwelling is the process in the sea by which the subsurface water moves up towards the surface. Wind-driven surface currents, with the coast to the left to the current in the northern hemisphere induces upward motion of subsurface waters near to the coast. The process brings up high nutrient bottom waters to the sunlit surface layers, thereby enhancing organic production, which in turn produces blooms of phytoplankton. Subsequently zooplankton thrives on them and together contribute good feeding grounds for the pelagic fishes. Thus the process of upwelling by way of a series of mechanisms triggers the life cycle in the sea and is of considerable importance in determining the subsequent fishery of the area of its influence.

Considerable amount of work has been done to unravel the causative factors favouring upwelling and its time of occurrence and duration along the west coast of India (Banse, 1959; Ramasastry and Myrland, 1960; Ramamirtham and Jayaraman, 1960; Varadachari and Sharma, 1964; Sharma, 1966; Bhargava, et al, 1973; Ramamirtham and Rao, 1973 and Anon B, 1976). Attempts were also made to study the intensity of upwelling in the area

(Ramamirtham and Rao, 1973; Lathipha and Murty, 1978; Anon, 1980; and Murty, 1981).

The commencement of upwelling at deeper layers off the south-west coast of India is observed to start in February. It is caused by the northerly wind, which transports the surface waters away from the coast due to Ekman effect and in turn initiates the vertical ascent of subsurface water (Anon B, 1976). The onset of the south-west monsoon, with the strongest wind in the western part of the Indian Ocean generates a clockwise circulation in the northern Indian Ocean. This develops into a relatively strong southerly current at the surface levels along the west coast of India (Lighthill, 1969). This current is responsible for the further continuance of upwelling. Thus, upwelling is wind generated prior to the onset of the south-west monsoon and thereafter it is mainly caused by the large scale current circulation.

In the present study, the time of commencement, intensity and duration of upwelling along the different sections in the Cape Comorin - Ratnagiri region during the 1972-75 period are discussed. For the purpose, the time of occurrence of maximum and the corresponding minimum temperature values at three different depth points (10 metre depth near to the coast, 50 metre depth in the middle of the shelf and at 100 metre depth near to the edge of the shelf) are considered (Figs.32-37A). The variations in temperature at the very surface for the above three selected depth levels at each section have also presented along with (Figs.32-37B) to understand the relative variation of temperature brought about at surface during upwelling period within the shelf waters on account of air-sea interaction and insolation at the surface from the sun. The intensity and duration of upwelling was also studied by plotting the depth of occurrence of the 1 ml O_2/L layer and its variation with time for different sections (Fig.38).

The rate of fall of temperature (in °C/week) at the selected three above said depth levels were calculated for the upwelling periods of 1972-'75, for different sections and their mean values obtained (Table 2).and presented in fig.39 to represent the mean trend of the variations of upwelling intensity at different sections. The rate of ascent of 1 ml O_2/L layer (in m/week) was obtained for the individual years for the same different sections (Table-3) and their mean values were calculated and presented along with the mean rate of fall of temperature. The diagram presented represent the variations of upwelling intensity obtained by two approaches from two different parameters independent of each other. Both methods gave almost identical results regarding the

Table-2. Mean upwelling intensity at different regions as obtained from the mean rate of fall of temperature (in °C/week) at different depth points within the shelf waters of the respective regions for the upwelling period of 1972-75.

Sections	10 M	50 M	100 M	$\bar{x}$
Cape Comorin	0.29	0.29	0.32	0.30
Quilon	0.23	0.30	0.36	0.30
Cochin	0.31	0.37	0.33	0.34
Kasaragod	0.44	0.35	0.39	0.39
Karwar	0.28	0.35	0.38	0.34
Ratnagiri	0.11	0.26	0.21	0.19

trend in the variations of upwelling intensity in the selected region (Quilon-Karwar).

It is also observed from the above figures that the upwelling intensity was maximum in the region off Kasaragod and the intensity decreased on either side. This is in agreement with the earlier findings of Lathipha and Murty (1978) who observed that the effect of upwelling phenomenon was more pronounced in the region between Calicut and Mangalore along the west coast of India. Varadachari and Sharma (1964) reported large divergent zones in Cochin-Karwar area during the southwest monsoon period which can give rise to intense upwelling in these waters. Ramamirtham and Rao (1973) also observed that the phenomenon of upwelling is more intense in central part of the south-west coast of India.

Upwelling during 1972:

During this year upwelling in the Quilon-Ratnagiri area was observed from February to September. As a result water from about 140 m depth was found upwelled towards surface layers all along the coast (Fig.38). The intensity of the upward motion of the bottom waters varied considerably from place to place. In 1972 the upwelling intensity was found comparatively more in the Karwar section where an average temperature fall of 0.42°C per week was observed. Corresponding low intensity was recorded in the section off Ratnagiri where an average temperature fall of 0.24°C per week was observed (Table-4). The upwelled water remained at surface layers until September in most of the regions. Upwelling prevailed at surface levels for a maximum period of 72 days off Kasaragod, 57 days off Karwar and 45 days off Cochin and only for 5 days off Ratnagiri (Table-5). The presence of upwelled water was observed up to a depth zone of 20 - 30 metre only in the section off Quilon. Data were not available for the Cape Comorin section in the year 1972. Though the intensity of upwelling was low in the Kasaragod section (Table-4) when compared with that of Karwar, the duration of upwelling was found to be more (Figs.35 and 36). Likewise the effect of upwelling was minimum at surface level in Quilon section, where moderate upwelling intensity was recorded.

Upwelling during 1973:

The influence of upwelling was observed at about 100 metre depth in the Cape Comorin - Karwar region by April-May (Fig.38). But the process got initiated at the deeper levels (130 - 140 m) much earlier, in the sections off Cochin and Kasaragod. The effect of upwelling was noticed at 10 metre depth first in the Cape Comorin section by April-May and it was found to progressively extend towards north. The effect of upwelling was observed at 10 metre depth near to the coast by about the end of June in Cochin section and by the begining of August in the Kasaragod and Karwar sections. The upwelling period along the entire south-west coast for the year 1973 was found to be from April to August. Low oxygenated upwelled water (1 ml O_2/L) did not reach the surface layers in the section off Ratnagiri, but remained at about 50 metre depth till November. The upwelling intensity was found to be maximum in the Kasaragod section, where an average temperature fall of about 0.47°C per week was estimated. The upwelling intensity was found to be correspondingly very low south of Cochin and north of Karwar. The duration of upwelling was estimated in terms of the duration of occurrence of low oxygenated water at surface levels which was found to be more or less same for both the Kasaragod and Karwar sections, where the values recorded were about 96 days. The corresponding values recorded for Cochin section was 72 days (Table-5). The ascent of upwelled water was found to be limited to a depth zone upto 30 metre only off Quilon as in 1972, while in the section off Cape Comorin the low oxygenated upwelled water remained below 70 metre depth even at the peak period of upwelling (Fig.38).

Upwelling during 1974:

Upwelling was indicated at deeper levels (145 - 160 m) in the month of January in Cochin and Kasaragod sections. In the sections north and south of it upwelling commenced much later, in February-March period. The effect of upwelling was found persisting in the upper layers, upto September in Cochin-Kasaragod sections, where upwelling started comparatively earlier, while in the sections further north of it upwelling continued upto November in the Karwar section and upto December in the Ratnagiri section. The upwelling intensity was observed to be maximum in the section off Kasaragod, where an average temperature fall of 0.32°C per week was observed. The values at other sections indicated moderate or weak upwelling along the coast. The upwelled water remained at the surface layers for a maximum period of 118 days in the section off Kasaragod and Karwar. The corresponding value for Cochin section was only 51 days (Table-5). It was observed that in the northernmost section off Ratnagiri and in the southernmost sections off Cape Comorin and Quilon the low oxygenated upwelled water remained below 30 metre depth zone (Fig.30).

Upwelling during 1975:

In 1975 upwelling commenced at the deeper levels

(160 m) in January in the sections south of Karwar, while the process appeared to have started much later at 140 - 150 metre in the months of March and June in the northern sections off Karwar and Ratnagiri respectively. Upwelling lasted up to the end of August and begining of September in all the sections, except for Karwar, where the process continued to progress and persist until the end of October. But in the section off Cape Comorin the influence of upwelling at surface levels was very weak and upwelling ceased much earlier in June itself. Upwelling intensities were more or less same for Quilon, Cochin and Karwar sections, where an average temperature fall of 0.29°C per week observed. The prevalence of low oxygen water was found to stay for a comparatively shorter period in Cochin section (30 days), while for the Kasaragod and Karwar sections the values were 54 and 42 days respectively. A notable feature for the year 1975 as regards upwelling was that the process continued till the end of October in Karwar section, while at other sections of the south-west coast inclusive of the northermost section off Ratnagiri it ceased by the end of August (Fig.38).

The actual time of commencement of upwelling in deeper depths varied considerably from place to place and year to year. In general the upward shift of the bottom waters commenced from around 140 to 160 metres in January/February

Table-4 Intensity of upwelling at different regions for different years, obtained from the sectional mean rate of fall of temperature (^{o}C/week) during the upwelling period.

Sections	1972	1973	1974	1975
Cape Comorin		0.31 (0.25-0.34)	0.20 (0.18-0.23)	0.39 (0.33-0.46)
Quilon	0.27 (0.25-0.32)	0.33 (0.28-0.40)	0.27 (0.15-0.35	0.29 (0.23-0.33)
Cochin	0.32 (0.28-0.39)	0.39 (0.28-0.52)	0.32 (0.28-0.41)	0.29 (0.22-0.34)
Kasaragod	0.34 (0.27-0.40)	0.47 (0.33-0.59)	0.32 (0.21-0.52)	0.42 (0.30-0.55)
Karwar	0.42 (0.32-0.53)	0.38 (0.27-0.50)	0.26 (0.23-0.31)	0.29 (0.25-0.32)
Ratnagiri	0.24 (0.17-0.33)	0.20 (0.16-0.24)	0.17 (0.13-0.25)	0.21 (0.20-0.21)

(Figures within the bracket refer to the ranges of upwelling intensities came across at the corresponding sections).

Table-5. Duration of prevalence (in days) of upwelled water at the surface layer, as indicated by the presence of 1 ml/L dissolved oxygen in the inshore area within 20 m depth from the surface (Sectionwise/yearwise).

Sections	1972	1973	1974	1975
Cape Comorin		***	*	**
Quilon	*	*	*	*
Cochin	45	72	51	30
Kasaragod	72	96	118	54
Karwar	57	96	118	42
Ratnagiri	5	*	*	3

* Oxygen minimum layer reached to a depth of 30 m only

** Oxygen minimum layer reached to a depth of 50 m only

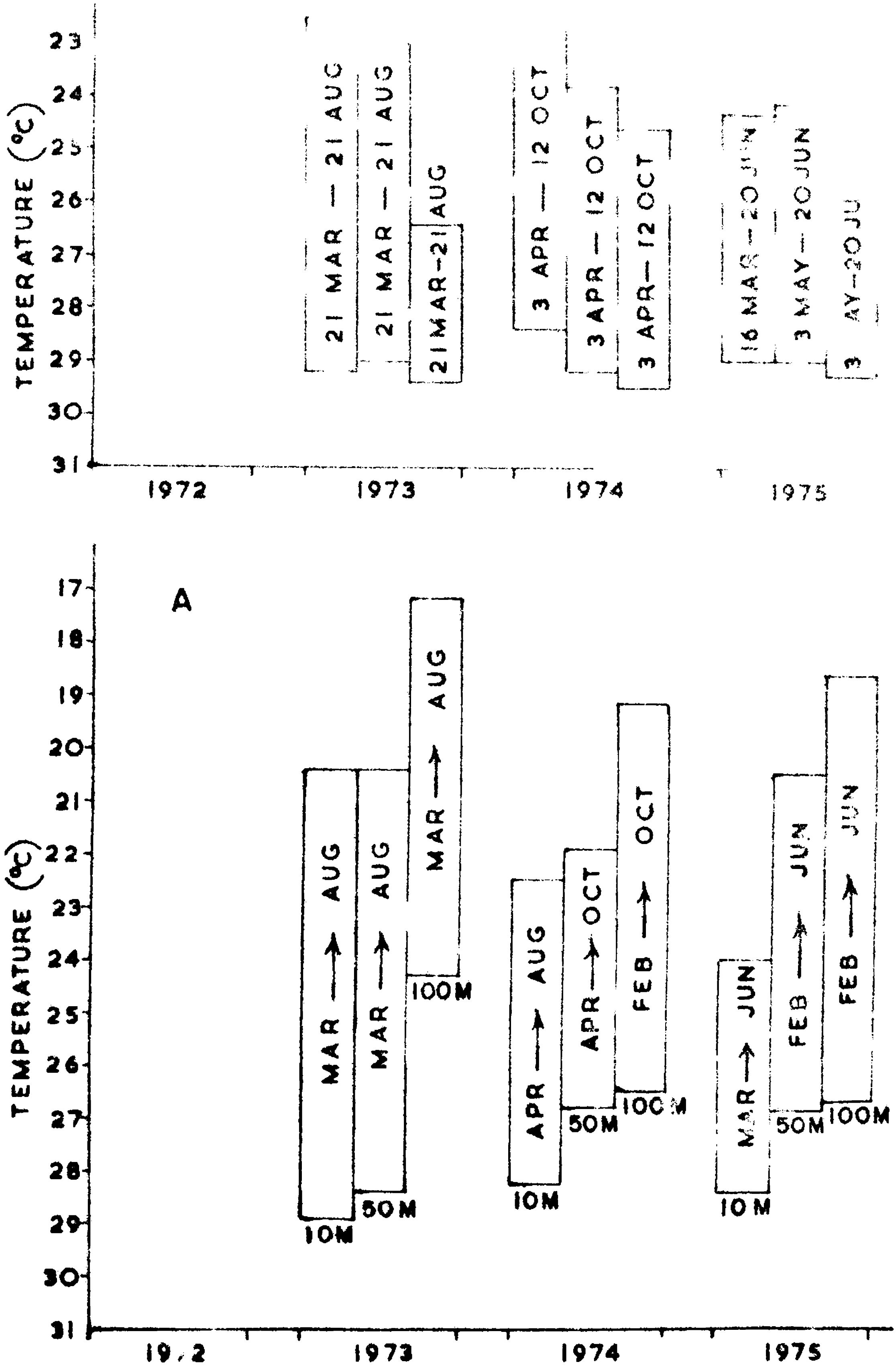
*** Oxygen minimum layer reached to a depth of 70 m only

(Fig.38). Ramamirtham and Rao (1973), reported that oxygen deficient waters of 75 - 100 metre depth have been drawn to upper layers due to upwelling. Sharma (1966) also stated that water at 100 metre depth moves upright from February onwards. The upwelled water reaches the surface layers in most of the sections, except in Ratnagiri, Quilon and Cape Comorin sections, where the low oxygenated upwelled water reaches to a depth below 30 metre only. Upwelling lasted upto August-September in southern sections and even to October-November in the northern sections off Kasaragod and Karwar. Earlier reports of Ramamirtham and Jayaraman (1960) that upwelling continued up to September or even October, of Sharma (1966), that upwelling persists upto July-August and that of Banse (1959) that upwelling continued up to September or even October are all based on specific areas with limited coverage. The upwelling intensity also varied considerably at different sections along the west coast of India. Ramasastry and Myrland (1960) reported that upwelling intensity varies along different areas of the coast and from year to year and Ramamirtham and Rao (1973) attributed this to the effect of changes in the wind field. The rate of upwelling in the coastal waters of the southwest coast of India by the middle of the south-west monsoon period, as observed by Murty (1981) is on average 0.35 metre per day.

FIGURE 32

A - The periods of upwelling and the corresponding temperature ranges at different depth points (at 10 m depth near to the coast, at 50 m depth in the middle of the shelf, and 100 m depth near to the edge of the shelf) off Cape Comorin. B - The annual ranges of surface temperature with the dates of occurrence of maximum and minimum corresponding to the depth points referred in A.

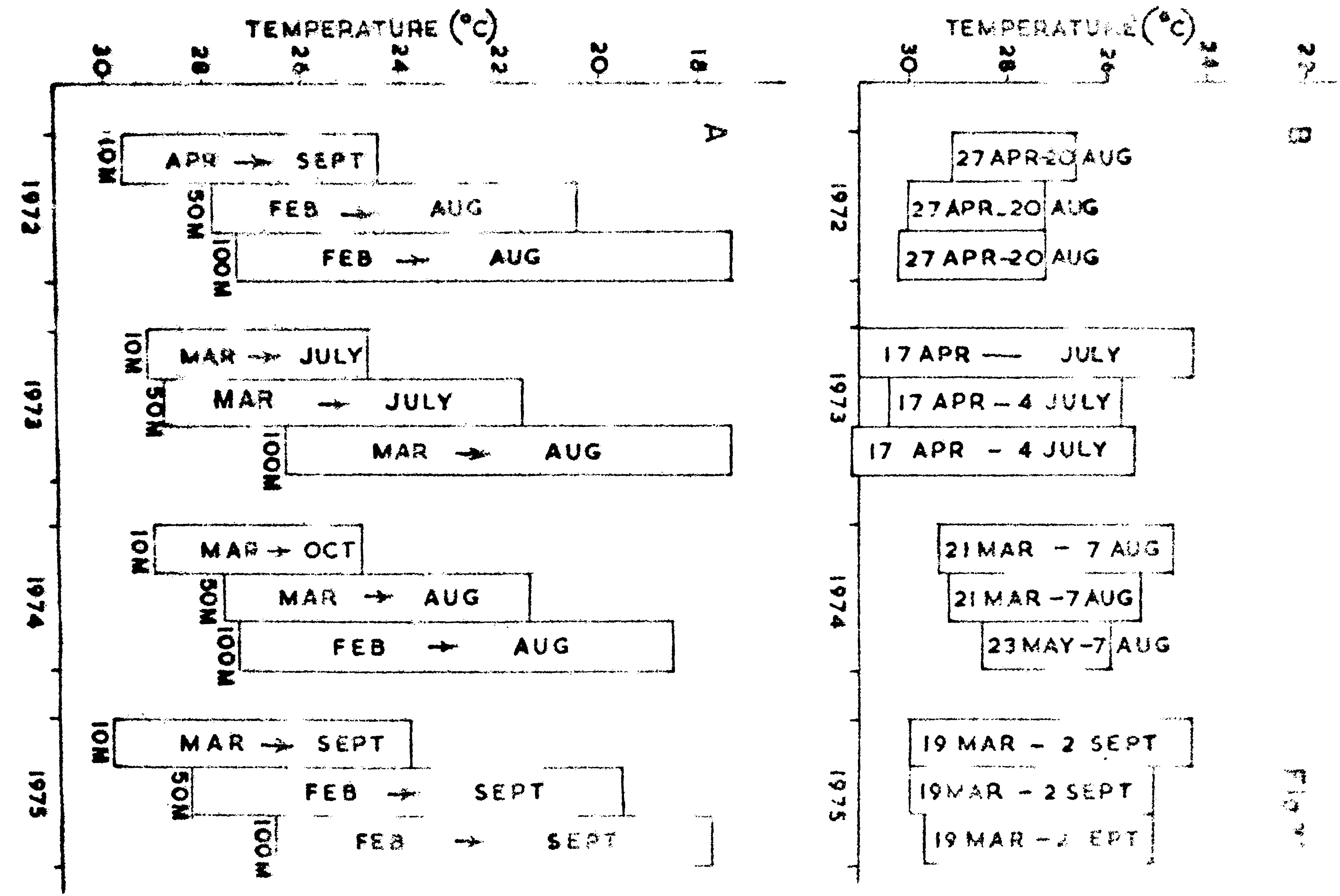
Fig 3a



B
TEMPERATURE (°C)
22
23
24
25
26
27
28
29
30
31
21 MAR — 21 AUG
21 MAR — 21 AUG
21 MAR–21 AUG
3 APR — 12 OCT
3 APR — 12 OCT
3 APR — 12 OCT
16 MAR – 20 JUN
3 MAY – 20 JUN
1972
1973
1974
1975
A
TEMPERATURE (°C)
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
MAR ⟶ AUG
MAR ⟶ AUG
MAR ⟶ AUG
APR ⟶ AUG
APR ⟶ OCT
FEB ⟶ OCT
MAR ⟶ JUN
FEB ⟶ JUN
FEB ⟶ JUN
10M
50M
100M
10M
50M
100M
10M
50M
100M
1973
1974
1975

FIGURE 33

A - The periods of upwelling and the corresponding temperature ranges at different depth points (at 10 m depth near to the coast, at 50 m depth in the middle of the shelf, and 100 m depth near to the edge of the shelf) off Quilon. B - The annual ranges of the surface temperature with the time of occurrence of maximum and minimum corresponding to the depth points referred in A.



TEMPERATURE (°C)
30
28
26
24
22
20
18
A
APR → SEPT
FEB → AUG
FEB → AUG
MAR → JULY
MAR → JULY
MAR → AUG
MAR → OCT
MAR → AUG
FEB → AUG
MAR → SEPT
FEB → SEPT
FEB → SEPT
10M
50M
100M
1972
1973
1974
1975
TEMPERATURE (°C)
B
27 APR-20 AUG
27 APR-20 AUG
27 APR-20 AUG
17 APR — JULY
17 APR - 4 JULY
17 APR - 4 JULY
21 MAR - 7 AUG
21 MAR -7 AUG
23 MAY -7 AUG
19 MAR - 2 SEPT
19 MAR - 2 SEPT

FIGURE 34

A - The periods of upwelling and the corresponding temperature ranges at different depth points (at 10 m depth near to the coast, at 50 m depth in the middle of the shelf, and 100 m depth near to the edge of the shelf) off Cochin. B - The annual ranges of surface temperature with the time of occurrence of maximum and minimum corresponding to the depth points referred in A.

Fig. 34

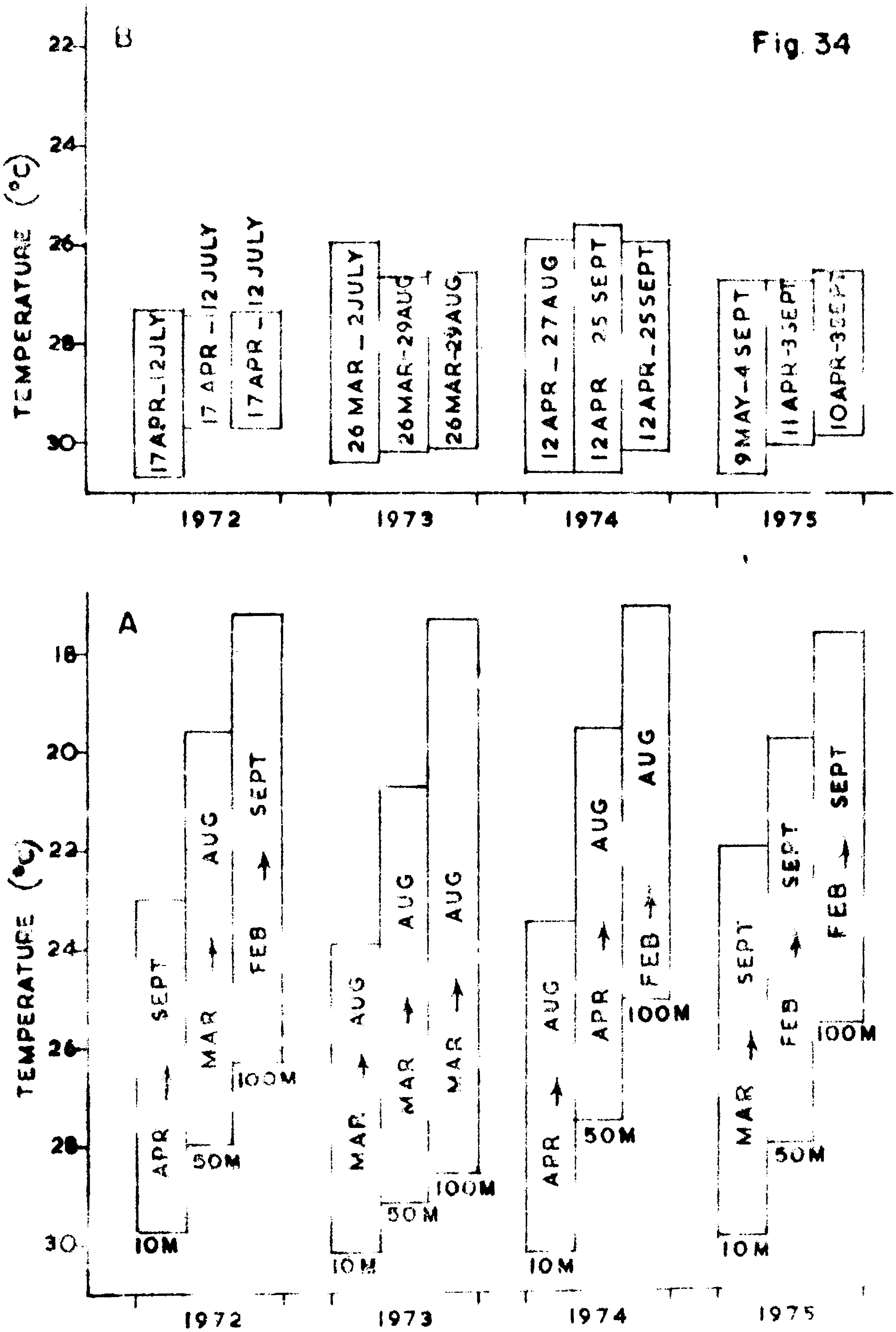

B
TEMPERATURE (°C)
22
24
26
28
30
17APR_12JLY
17 APR _12 JULY
17APR _12 JULY
26 MAR _ 2JULY
26MAR-29AUG
26MAR-29AUG
12 APR _ 27 AUG
12 APR 25 SEPT
12 APR_25 SEPT
9 MAY_4 SEPT
1972
1973
1974
1975
A
TEMPERATURE (°C)
18
20
22
24
26
28
30
APR → SEPT
MAR → AUG
FEB → SEPT
MAR → AUG
MAR → AUG
MAR → AUG
APR → AUG
APR → AUG
FEB → AUG
MAR → SEPT
FEB → SEPT
FEB → SEPT
10M
50M
100M
1972
1973
1974
1975

FIGURE 35

A - The periods of upwelling and the corresponding temperature ranges at different depth points (at 10 m depth near to the coast, at 50 m depth in the middle of the shelf, and 100 m depth near to the edge of the shelf off Kasaragod. B - The annual ranges of surface temperature with the time of occurrence of maximum and minimum corresponding to the depth points referred in A.

Fig. 35

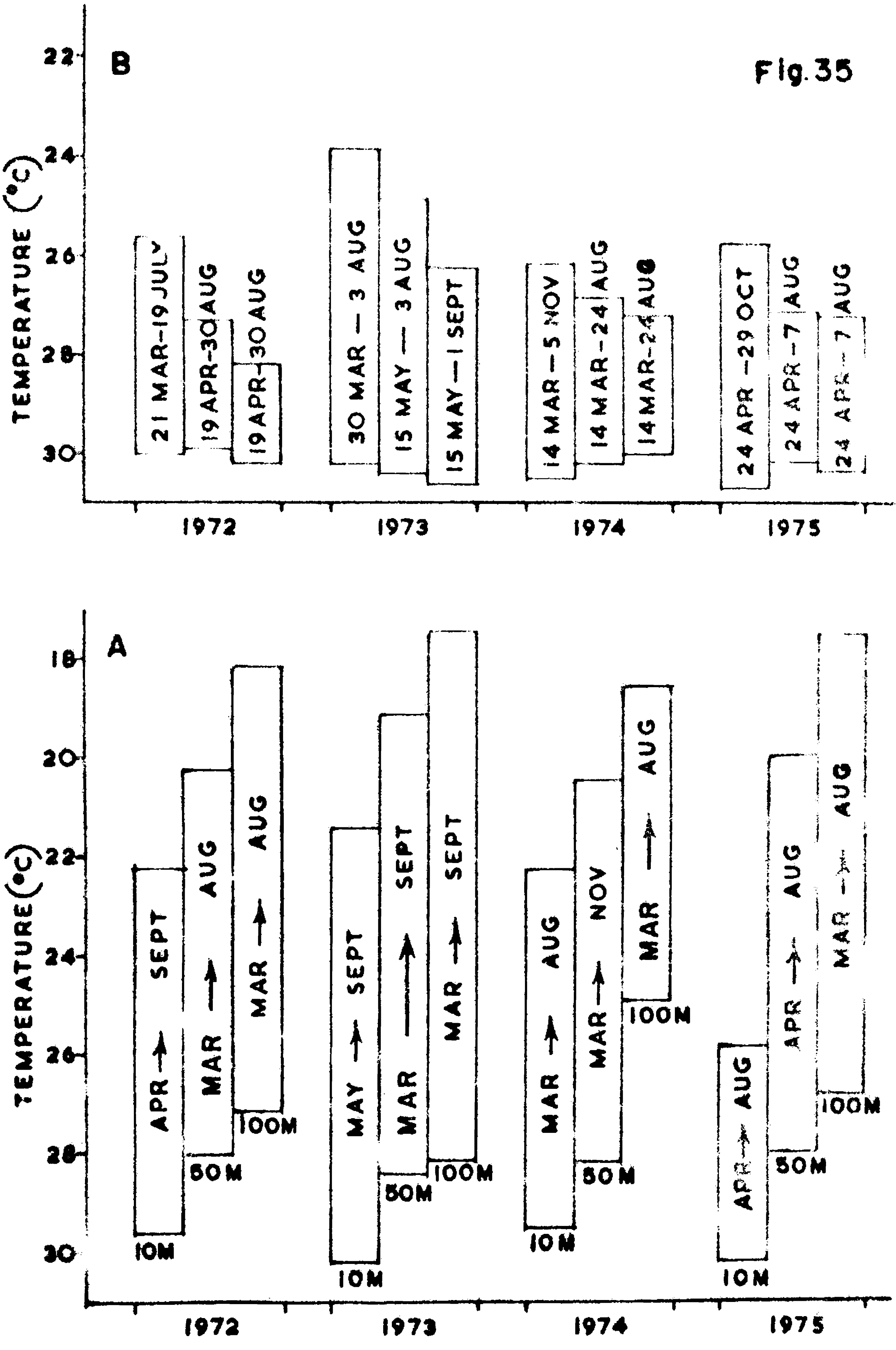

B
TEMPERATURE (°C)
22
24
26
28
30
21 MAR-19 JULY
19 APR-30 AUG
19 APR-30 AUG
30 MAR — 3 AUG
15 MAY — 3 AUG
15 MAY — 1 SEPT
14 MAR — 5 NOV
14 MAR-24 AUG
14 MAR-24 AUG
24 APR -29 OCT
24 APR-7 AUG
24 APR - 7 AUG
1972
1973
1974
1975
A
TEMPERATURE (°C)
18
20
22
24
26
28
30
APR → SEPT
MAR → AUG
MAR → AUG
MAY → SEPT
MAR → SEPT
MAR → SEPT
MAR → AUG
MAR → NOV
MAR → AUG
APR → AUG
APR → AUG
MAR → AUG
10M
50M
100M
1972
1973
1974
1975

FIGURE 36

A - The periods of upwelling and the corresponding temperature ranges at different depth points (at 10 m depth near to the coast, at 50 m depth in the middle of the shelf, and 100 m depth near to the edge of the shelf) off Karwar. B - The annual ranges of surface temperature with the time of occurrence of maximum and minimum corresponding to the the depth points referred in A.

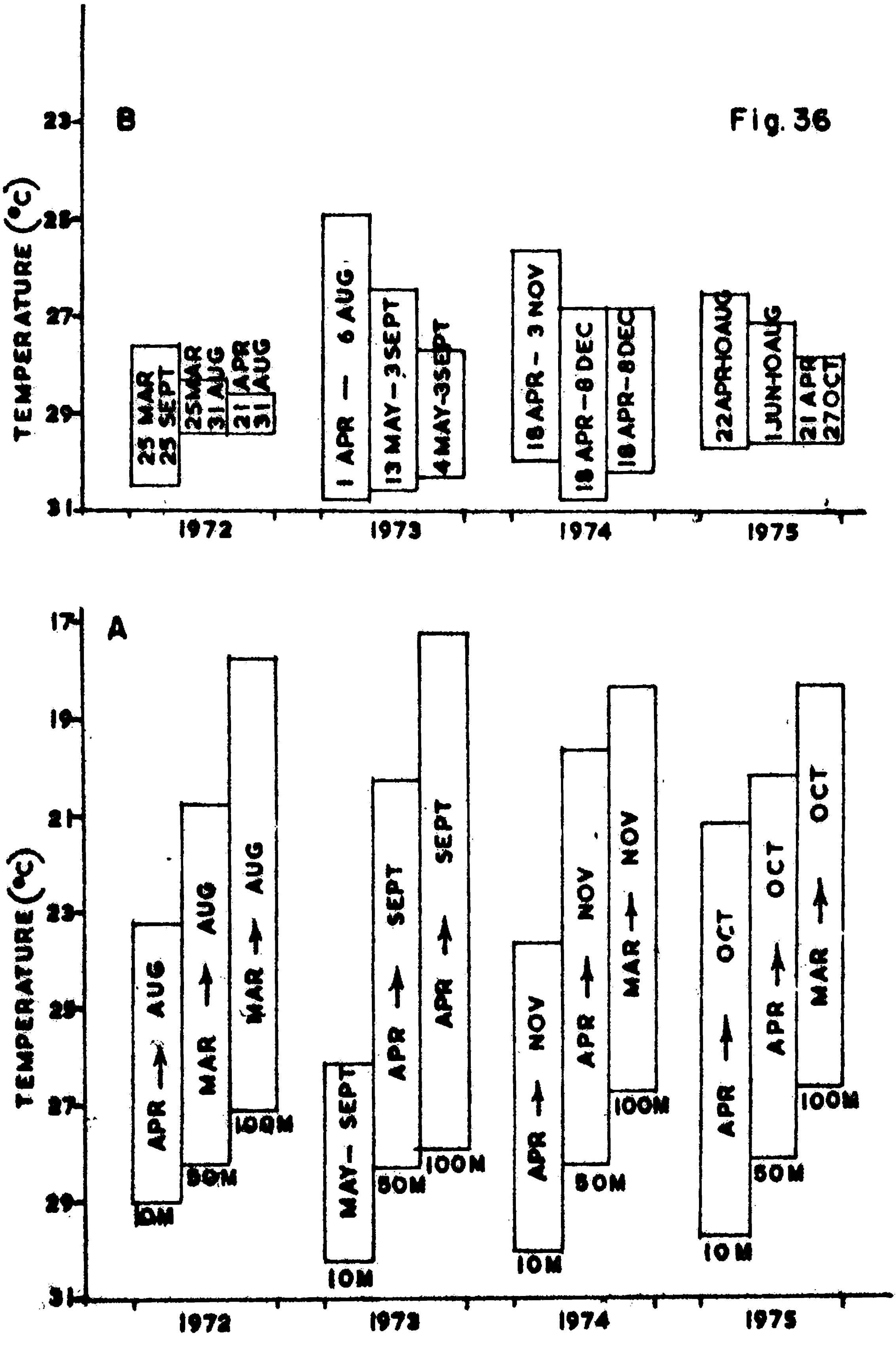

B
Fig. 36
TEMPERATURE (°C)
23
25
27
29
31
25 MAR 25 SEPT
25 MAR 31 AUG
21 APR 31 AUG
1 APR — 6 AUG
13 MAY – 3 SEPT
4 MAY – 3 SEPT
18 APR – 3 NOV
18 APR – 8 DEC
18 APR – 8 DEC
22 APR – 10 AUG
1 JUN – 10 AUG
21 APR 27 OCT
1972
1973
1974
1975
A
TEMPERATURE (°C)
17
19
21
23
25
27
29
31
APR → AUG
MAR → AUG
MAR → AUG
10M
50M
100M
MAY – SEPT
APR → SEPT
APR → SEPT
10M
50M
100M
APR → NOV
APR → NOV
MAR → NOV
10M
50M
100M
APR → OCT
APR → OCT
MAR → OCT
10M
50M
100M
1972
1973
1974
1975

FIGURE 37

A - The periods upwelling and the corresponding temperature ranges at different depth points (at 10 m depth near to the coast, at 50 m depth in the middle of the shelf, and 100m depth near to the edge of the shelf) off Ratnagiri. B - The annual ranges of surface temperature with the time of occurrence of maximum and minimum corresponding to the depth points of A.

Fig 3

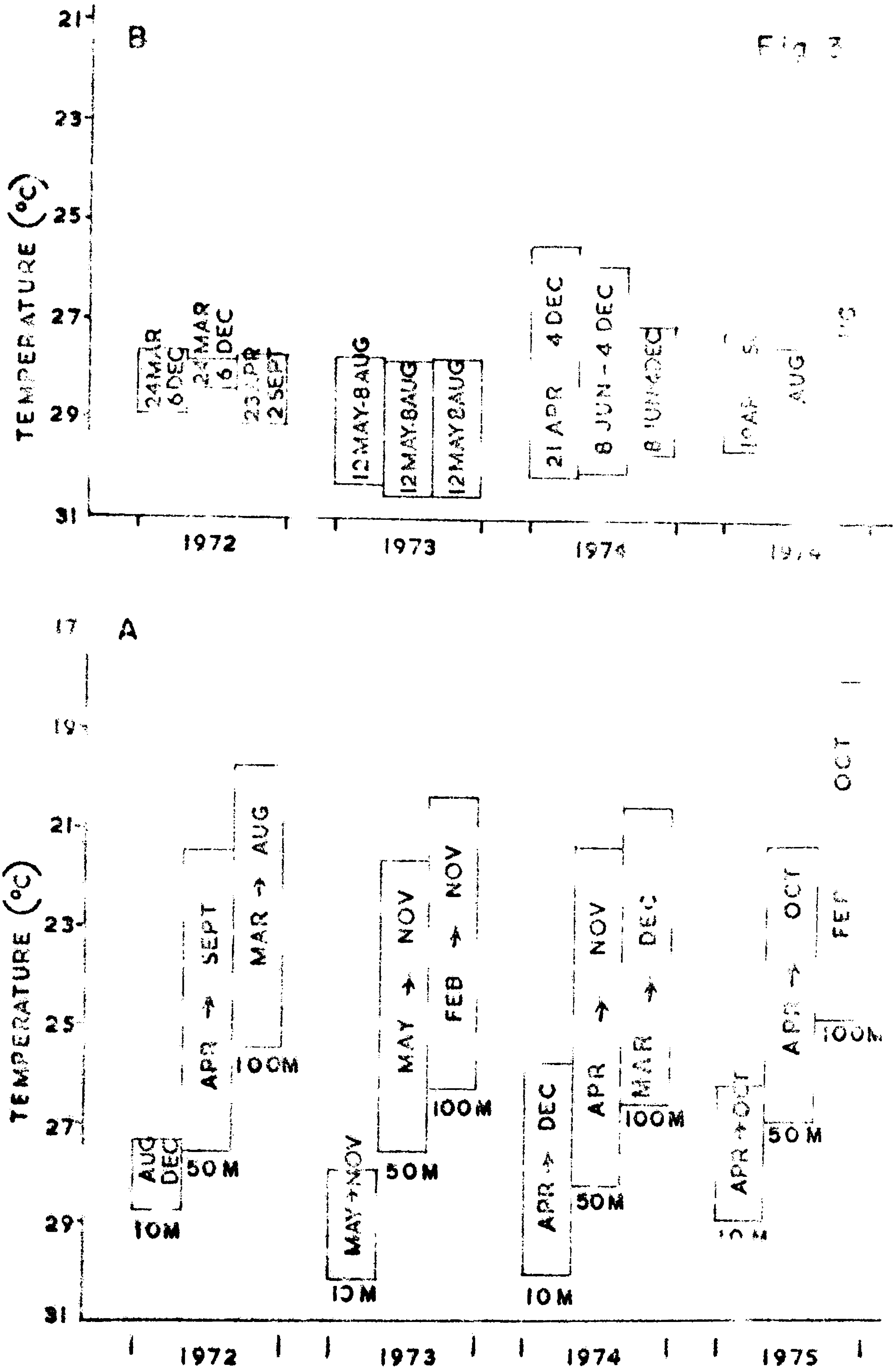

B
A
TEMPERATURE (°C)
21
23
25
27
29
31
17
19
24 MAR 6 DEC
24 MAR 6 DEC
23 APR 2 SEPT
12 MAY-8 AUG
12 MAY 8 AUG
12 MAY 8 AUG
21 APR 4 DEC
8 JUN - 4 DEC
AUG
1972
1973
1974
1975
AUG DEC
10 M
APR → SEPT
50 M
MAR → AUG
100 M
MAY → NOV
MAY → NOV
FEB → NOV
APR → DEC
APR → NOV
MAR → DEC
APR → OCT
APR → OCT
FEB
OCT
100 M

FIGURE 38

Vertical oscillation of the oxygen minimum layer (1 ml O_2/L) at different sections in the Cape Comorin - Ratnagiri region (1972-75 period).

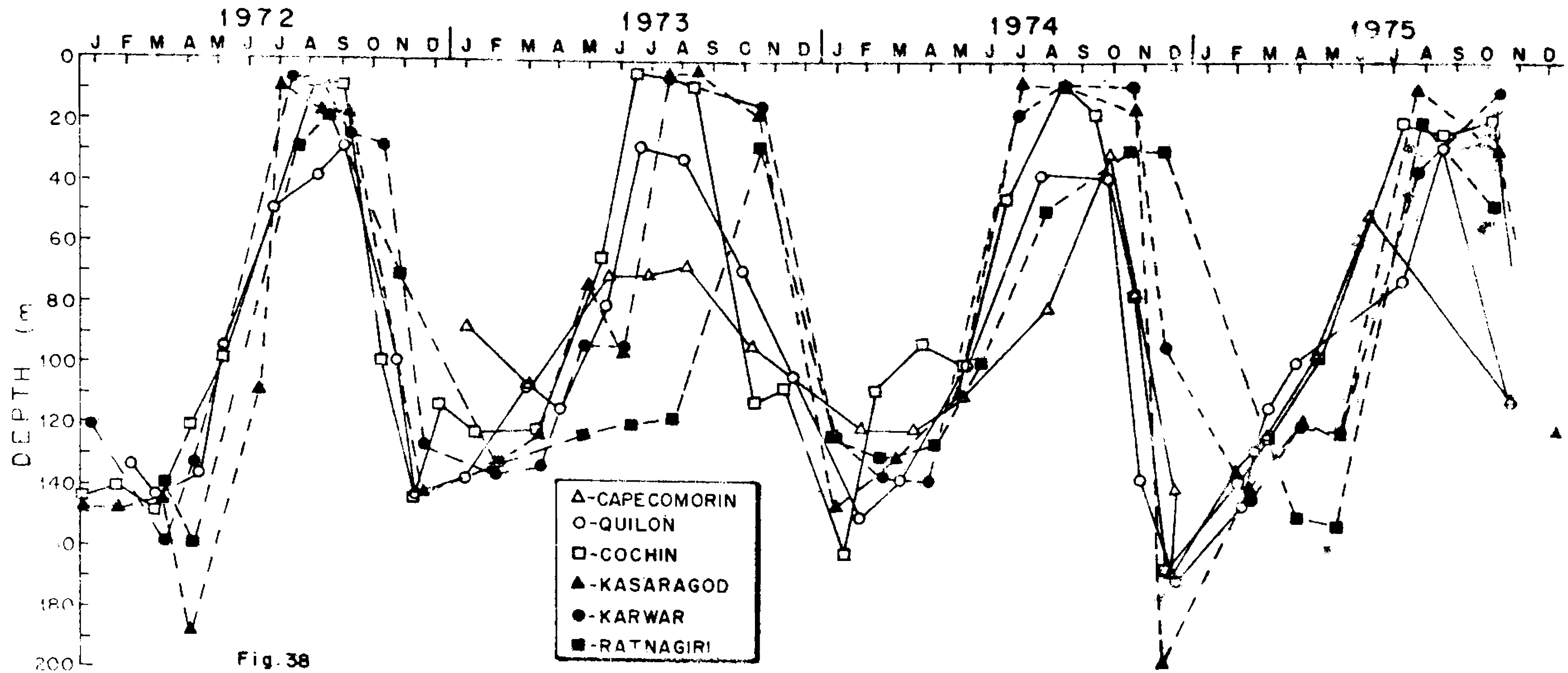

1972
1973
1974
1975
J F M A M J J A S O N D
DEPTH (m
0
20
40
60
80
100
120
140
180
200
Δ-CAPE COMORIN
O-QUILON
□-COCHIN
▲-KASARAGOD
●-KARWAR
■-RATNAGIRI

Fig. 38

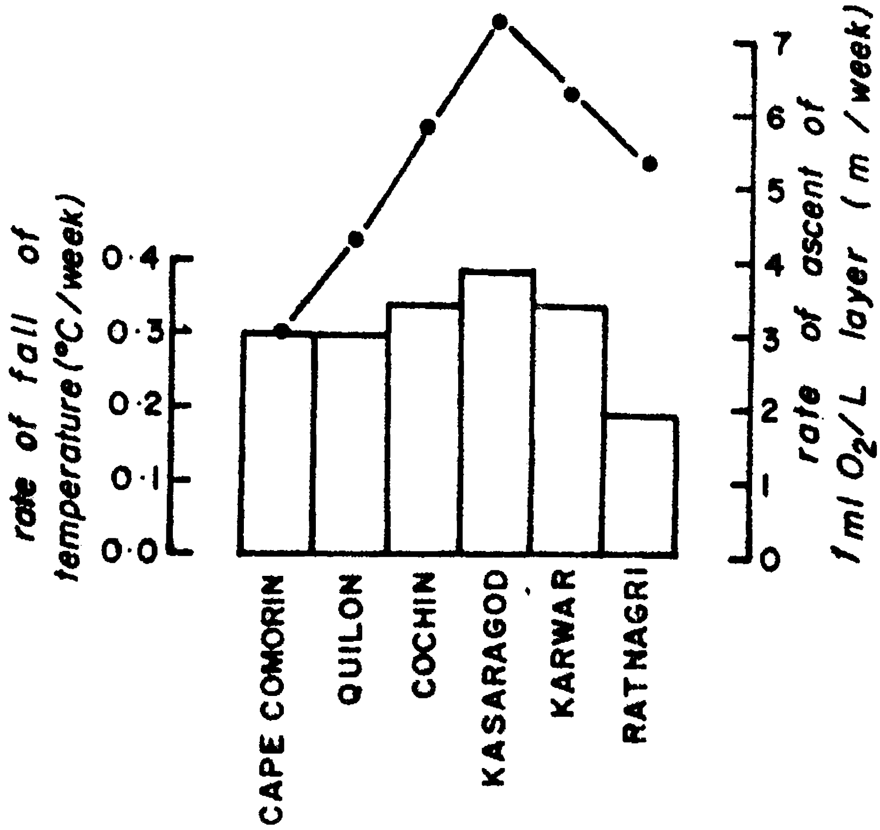
FIGURE 39

Regional changes of the intensity of upwelling as indicated by the rate of fall of temperature and the rate of ascent of O_2 minimum layer.

(Histogram - Rate of fall of temperature;

o——o Rate of ascent of 1 ml/L O_2)

Fig. 39



rate of fall of temperature (°C / week)
0·0
0·1
0·2
0·3
0·4
rate of ascent of 1 ml O_2/L layer (m / week)
0
1
2
3
4
5
6
7
CAPE COMORIN
QUILON
COCHIN
KASARAGOD
KARWAR
RATNAGRI

According to some other observations (Anon B, 1976) the average rate of upwelling in coastal water judging from the ascent of the low oxygen water appears not to exceed 0.8 metre per day. The author's observation on upwelling intensity based on the rate of ascent of the oxygen minimum layer indicated a range of 2.76 - 7.10 metre per week. In the present study the upwelling intensity was observed to be maximum in the section off Kasaragod where a temperature fall of 0.06°C per day was observed.

No regularity was observed in the time of commencement, intensity and duration of upwelling from section to section and year to year. The duration of upwelling was found to be more in some sections, where moderate or weak upwelling intensities were recorded or vice versa. However, the middle region along the coast namely Cochin - Karwar showed more intense upwelling and the intensity decreased on either side.

5.2 Vertical stability of the water layers

Vertical stability values in the water column along the west coast of India were calculated for the sections off Quilon, Kasaragod and Ratnagiri, representing the southern, central and northern regions. The year 1974 has been chosen for the above study, as the periodicity of working out the above sections was maximum during this year. The criterion chosen for stability determination is $E = 10^{-3} \frac{d\sigma_t}{dz}$ where E is stability, $\frac{d\sigma_t}{dz}$ is vertical gradient of density at depth Z (Sverdrup et al, 1942).

High value of stability were observed at surface layer in the southern region in November. Stability values showed gradual decrease towards bottom during this period indicating less stable conditions in the water column (Table 6). In wide contrast to the November condition, the stability values in December were very low and negative values were recorded at surface layers which indicated the presence of highly unstable water susceptable to vertical mixing. A stable water column was present in 20 - 30 metre layer within the shelf preventing any intrusion of the bottom water to the upper layers during this period. In both November and December, stable conditions prevailed at the deeper layers in stations situated at the edge of the shelf. The stability values at all stations in the central region within the shelf in August-November period shows decrease towards bottom, indicating less stable conditions (Table-7). Ramamirtham and Aravindakshan Nair (1964) attributed this to the effect of upwelling and vertical turbulance of the monsoon and post monsoon seasons.d During December, alternatively high and low stability values were observed indicating extreme turbulent conditions. Similar conditions, characteristic of winter were also observed by Sastry (1957).

Both in the Southern and central regions, negative values or low values of stability were observed at the surface in December, indicating unstable condition. This can be attributed to the decrease in temperature at the surface layers due to the winter cooling, which made higher density water at surface susceptible to sinking. This situation gives rise to an unstable condition at these layers favourable for constant mixing.

However, generally in the upper layers close to the coastal stations, stable conditions were observed both in southern and central regions during the hot weather season. In the month of May, 0 - 30 metre depth layer was found to be stable in these regions. But unstable conditions continued to persist at deeper layers near to the continental shelf edge throughout this period. As the monsoon set in, the stability of the water column within the shelf got disturbed due to the considerable amount of mixing taking place near to the coast during this period. By November, the water column upto 20 metre depth got stabilised and by winter, temperature inversions were observed at subsurface layers, which gave rise to negative or low values of stability and unstable conditions in these layers.

Table-6 Vertical stability values (expressed as $10^8 E$) obtained at different stations within the shelf waters off Quilon (1974).

+ Positive stability   0 Neutral stability   − Negative stability

Depth-interval (m)	FEBRUARY				MARCH				MAY			
	1	2	3	4	1	2	3	4	1	2	3	4
0 - 10	+1000	+1800	-0-	+2500	+4600	+400	-0-		+8900	+600	+1100	+1200
10 - 20			+4900			+1600	+1400			+7300	+2700	+5400
20 - 30			+1900			+2100	+800			+2500	+7300	+5800
30 - 50		+3900	+3550	+150		+400	+1000	+5350		+2300	+3800	+1150
50 - 75			+1650	+960			+4240	+3120			+1450	+2080
75 - 100				+1480				+2600			+700	+2400

Depth-interval (m)	AUGUST				NOVEMBER				DECEMBER			
	1	2	3	4	1	2	3	4	1	2	3	4
0 - 10	+7400	+1100	+700	-500	+5000	+10200	+17300	+4600	-300	-300	+200	+100
10 - 20		+5300	+5500	+3600		+2200	+2400	+300		-0-	+1200	
20 - 30		+2400	+4600	+6300		+500	+1100	+900		+5000	+7600	
30 - 50		+900	+1650	+2750		+450	+1050	+1850			+1450	
50 - 75			+1000	+1440			+1080	+2520			+680	+2820
75 - 100				+1418			+1440	+2320				+3040

Table-7 Vertical stability values (expressed as 10^8E) obtained at different stations within the shelf waters off Kasaragod (1974).

+ Positive stability 0 Neutral stability - Negative stability

Depth-interval (m)	JANUARY					MARCH				
	1	2	3	4	5	1	2	3	4	5
0 - 10	+800	-0-	+400	-0-	+3800	+3000	+2500	+2100	+1600	+900
10 - 20		+900	+100	+3000	+100		+2600	+300	+300	+100
20 - 30		+200	-0-	+100	-100		+7700	+5800	+1700	+4500
30 - 50			+6900	+2900	+ 1600			+4450	+3100	+2750
50 - 75				+8040	+7920				+8840	+4440
75 - 100				+2240	+4240				+2200	+2800

Depth-interval (m)	MAY					JULY				
	1	2	3	4	5	1	2	3	4	5
0 - 10	+11300	-0-	+800	+900	+800		+7200	-500	+200	+200
10 - 20		+100	+100	+600	+2000		+12500	+5500	+1900	+2500
20 - 30		+4400	+3900	+500	+1800		+1200	+11600	+15100	+13300
30 - 50		+14900	+8700	+9250	+6200			+1600	+2900	+2050
50 - 75			+1133	+2120	+3680				+200	+1120
75 - 100				+440	+960				+320	+1000

Table-7 (continued)

Depth-interval (m)	AUGUST					NOVEMBER				
	1	2	3	4	5	1	2	3	4	5
0 - 10			+30100	+5800	+100	+10900	+19400	+8600	+4200	+1200
10 - 20		+1400	+3000	+19600	+2300		+3700	+13000	+1200	+4100
20 - 30		+500	+300	+4500	+17400		+500	+3300	+4400	+9100
30 - 50		+1700	+1350	+1500	+1500		-0-	+400	+3000	+4500
50 - 75				+1120	+1560			-0-	+800	+1120
75 - 100				+1080	+1000				+400	+960

Depth-interval (m)	DECEMBER				
	1	2	3	4	5
0 - 10	-0-	+300	+400	+4500	+2300
10 - 20		+400	+2300	+3700	+5800
20 - 30		+600	+200	+3200	+1500
30 - 50		+250	+1100	+1800	+1950
50 - 75				+480	+1000
75 - 100				+1480	+520

In the northern region the stability conditions of water column within the shelf were found considerably different from that of the other sections south of it (Table-8). The influence of higher salinity Arabian sea water persisted during most part of the year, coupled with relatively low intensity of the south-west monsoon and weak upwelling, contributed much to the highly varied conditions in this region. Thus, in contrast to the conditions of the southern sections, the stability values within 0 - 20 metre depth layer of Ratnagiri showed negative values in most of the observations in different months of the year. The temperature data also showed the presence of a weak thermal gradient at surface layers, which in turn contributed to the lesser values of stability. These unstable conditions could be expected on account of the characteristic cell like structures in temperature distribution at surface levels (Fig.22).

The stable column was found to be deeper at off shore stations during March. By April the pattern considerably changed and negative values of stability were observed at many places within the shelf in the 0 - 20 metre layer. A stable layer was found within 20 - 30 metre depth zone. In June, coastal stations upto a depth of 50 metres showed highly stable conditions. Negative values of stability were also encountered in the upper 0 - 10 metre layer near the shelf edge, where unstable conditions prevailed during this period of the year.

August was observed to be a period with stability values within the shelf station showing alternatively increasing and decreasing values throughout column, indicative of lateral mixing during this period.

In December, vertical mixing was found to take place again in the surface layers at offshore stations as indicated by the negative values of stability, while shallow coastal waters exhibited a tendency to stabilise itself during this period. Negative values observed in January at the bottom levels at offshore stations indicated vertical mixing taking place and low stability values at surface layers in coastal stations bore the mark of instability.

The absence of both the strong vertical thermal gradient and the influence of low salinity water in considerable amount, as in the case of the southern section, contributed to the unstable conditions in these waters during most part of the year.

The mean values of stability parameter for three discret seasons namely, the Hot weather season, the South-west monsoon season and the North-east monsoon season are studied, for the two discret columns of water (0 - 20 metre) and (50- 100 metre) for the Southern (Quilon) Central

Table-8. Vertical stability values (expressed as $10^8 E$) obtained at different stations within the shelf waters off Ratnagiri (1974)

\+ Positive stability 0 Neutral stability - Negative stability

Depth-interval (m)	JANUARY							MARCH						
	1	2	3	4	5	6	7	1	2	3	4	5	6	7
0 - 10	+200		+800		-0-	-700	-0-	-100	+200	-200	+200	-100	+200	+300
10 - 20			+200		-0-	+200	-100		+2300	+3000	+3700	-0-	+1100	+900
20 - 30		+200	+4600	+2300	+700	+600	+2600		+4700	+4200	+3900	+6100	+1400	+900
30 - 50			+40	+360	+700	-0-	-1250			+1400	+1150	+2350	+3750	+3250
50 - 75						+120	-40						+600	+2360
75 - 100														+2120

Depth-interval (m)	APRIL							JUNE						
	1	2	3	4	5	6	7	1	2	3	4	5	6	7
0 - 10	-200	+200	+300	+100			+100	+2200	-0-	+100	-100	-100	-200	-300
10 - 20		+700	-100	+100	-0-	+200	+100		+1300	+300	+300	+100	+100	-0-
20 - 30			+900	+5900	+7100	+7500	+5700		+10700	+100	+600	+300	-0-	+100
30 - 50			+2000	+3120	+4150	+3900	+3800			+6800	+6600	+6050	+6250	+7500
50 - 75						+4700	+2600					+5240	+3480	+1720
75 - 100														+2520

Table-8 (continued).

Depth-interval (m)	AUGUST							NOVEMBER						
	1	2	3	4	5	6	7	1	2	3	4	5	6	7
0 - 10		+100	+300	-100	+200	-0-	+200	+4800		+600	+100	+500	+600	+400
10 - 20		+18700	-0-	-300	-0-	-0-	+300		+19000	+19100	+19900	+20200	+1600	+3000
20 - 30		+8300	+13800	+10600	+100	+200	+200		+2500	+3300	+4600	+8900	+11600	+3200
30 - 50			+4300	+5100	+7550	+6450	+100			+150	+700	+700	+4200	+8000
50 - 75					+3500	+2320	+6440						+3880	+1520
75 - 100														+1960

Depth-interval (m)	DECEMBER						
	1	2	3	4	5	6	7
0 - 10	+3300	-0-	+300	-0-	-200	-100	+600
10 - 20		+8500	+700	+1700	+100	+700	-300
20 - 30		+1500	+2300	+6600	+1700	+2100	-100
30 - 50			+4200	+2200	+5400	+4850	+300
50 - 75						+1040	+4200
75 - 100							+1600

(Kasaragod) and northern (Ratnagiri) sections within the shelf waters. It may be generally stated that the top layer (0 - 20 metres) of water is relatively more stable than the layer below it (50 - 100 metres) during any season in the southern and middle regions, while the reverse is the case for the north.

CHAPTER 6

6 INFLUENCE OF THE HYDROLOGICAL CONDITIONS ON PLANKTON OF THE AREA UNDER STUDY

6.1 Seasonal distribution of zooplankton

Zooplankton biomass showed cyclic seasonal variations in distribution along the west coast of India. Its abundance and distribution greatly influence the availability and distribution of plankton-feeding pelagic fishes.

Along the south-west coast the peak of occurrence of zooplankton generally follows in close sequence, the primary production of phytoplankton triggered by upwelling phenomenon. The process brings in high nutrient bottom water to the surface layers, which are utilised for the production of blooms of phytoplankton. This is followed by production of swarms of zooplankton thriving on the plankton blooms.

Studies on zooplankton biomass along the south-west coast (Menon and George, 1977) indicated low values over the shelf from January to April. The peak is observed during the July - September period. They reported a secondary peak in November, and also a shoreward shift in plankton until December, especially in the southern areas, with the distribution then becoming patchy and the abundance reduced. While studying the plankton of the North Kanara coast, Ramamurthy (1965) reported that the south-west monsoon and the immediate post monsoon period (July to November) are the most productive periods for plankton. According to him the zooplankton biomass attains the peak during August-November period. Recent investigations by Pelagic Fishery Project (Anon, 1974) indicated that the high plankton production closely followed upwelling in the region.

It is observed from the present study that, in general low values of zooplankton biomass was observed in January-March period along the coast in the Quilon-Karwar region. The mean monthly values of plankton volume within the shelf off Quilon for the 1972-75 period was found to be ranging between 0.08 - 0.18 ml/m^3 of water (Table-9). An increase in value of mean plankton volume was noticed within the shelf from April onwards, in the Quilon-Karwar region and the peak was observed in the July-September period (Fig.40). It appears from the data (Table-9) that the peak is attained earlier in the southern region. The plankton volumes decreased considerably from September onwards in the region off Quilon and Cochin, while towards north (off Kasaragod and Karwar) the plankton biomass remained high even upto December (Fig.40). Monthly mean values for October-December period during 1973-75, indicated the maximum abundance of zooplankton

Table-9 Average plankton density within the shelf waters off Quilon, Cochin, Kasaragod and Karwar for the different seasons of 1972-'75 period (ml/m^3 of water).

Year	Section / Months	Quilon	Cochin	Kasaragod	Karwar
1972	Jan.- Mar.	0.08	0.08	0.09	0.09
	Apr.- Jun.	0.12	0.32	0.17	0.14
	Jul.- Sep.	0.77	0.60	0.64	0.46
	Oct.- Dec.	0.16	0.29	0.03	0.54
1973	Jan.- Mar.	0.17	0.21	0.09	0.35
	Apr.- Jun.	0.33	0.51	0.26	0.29
	Jul.- Sep.	0.42	0.70	0.80	0.43
	Oct.- Dec.	0.26	0.33	0.72	0.53
1974	Jan.- Mar.	0.12	0.21	0.20	0.13
	Apr.- Jun.	0.27	0.36	0.22	0.16
	Jul.- Sep.	0.75	0.54	0.35	0.57
	Oct.- Dec.	0.32	0.32	0.83	0.49
1975	Jan.- Mar.	0.18	0.11	0.47	0.18
	Apr.- Jun.	0.18	0.14	0.15	0.23
	Jul.- Sep.	0.64	0.54	0.27	0.16
	Oct.- Dec.	-	-	0.70	0.18

FIGURE 40

Seasonal distribution of plankton biomass (in ml/m^3 of water) at Quilon, Cochin, Kasaragod and Karwar during 1972-75 period.

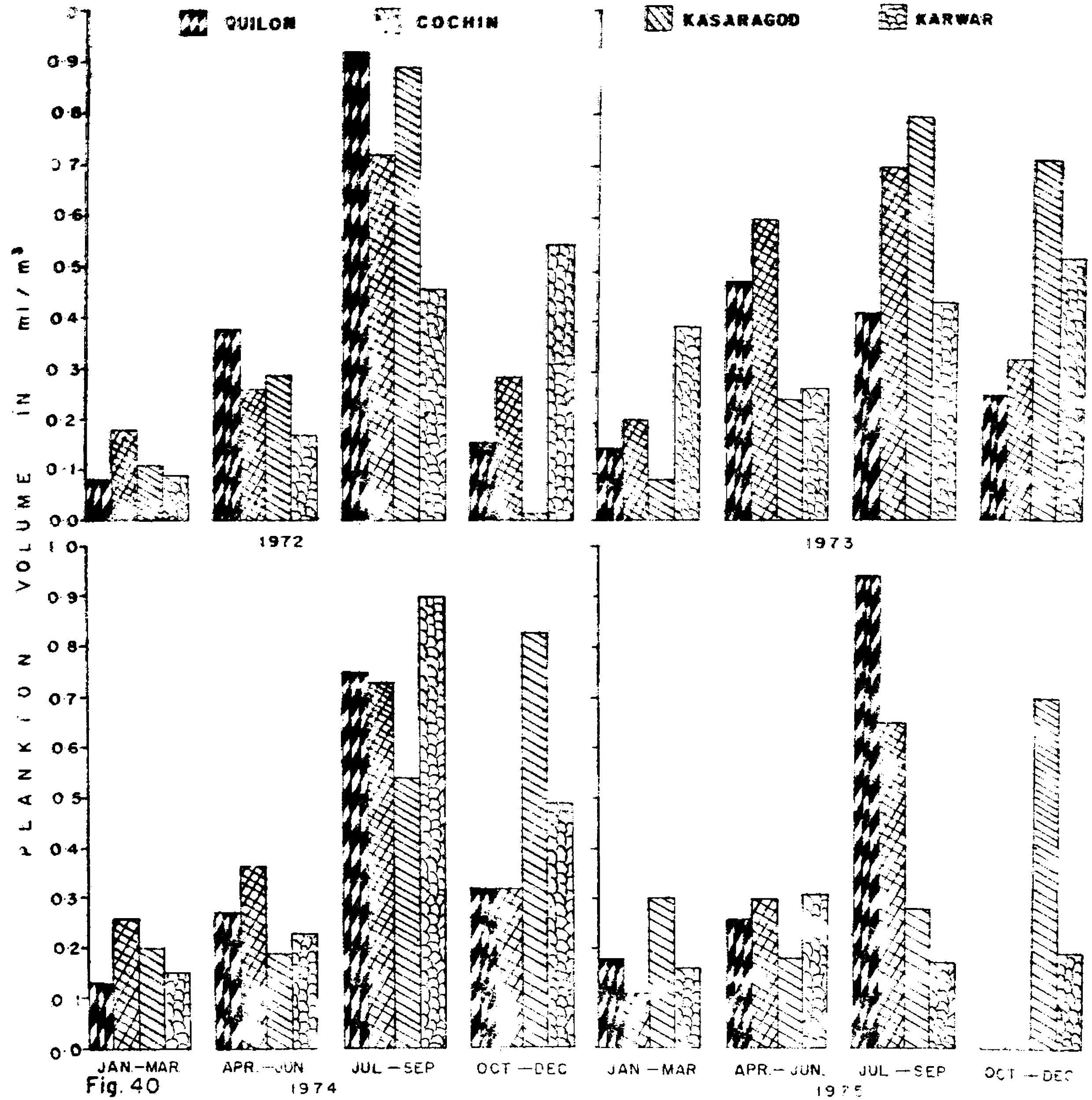

QUILON
COCHIN
KASARAGOD
KARWAR
PLANKTON VOLUME IN ml / m³
0·0
0·1
0·2
0·3
0·4
0·5
0·6
0·7
0·8
0·9
1·0
1972
1973
JAN.–MAR.
APR.–JUN.
JUL.–SEP.
OCT.–DEC.
JAN.–MAR.
APR.–JUN.
JUL.–SEP.
OCT.–DEC.
1974

Fig. 40

biomass (0.70 - 0.83 ml/m^3) in the Kasaragod section, with the lowest values observed off Quilon. The distribution pattern of plankton biomass for the Cochin section showed the occurrence of a secondary maximum in November-December period (Fig.41).

6.2 Influence of upwelling on zooplankton

An attempt is made here to establish the relation of the distributions of plankton biomass and upwelling covering the area from Quilon to Karwar for the 1972-75 period. The vertical movement of the 1 ml O_2/L layer is taken as the indicator of upwelling. The depth of occurrence of 1 ml O_2/L layer is plotted against time, to show the pattern of the process of upwelling with the intensity and duration in its occurrence. The average zooplankton biomass (ml/m^3) within the shelf is also plotted in a similar way for different sections and interposed with the former, to study the influence of upwelling on plankton production (Figs. 41 and 42).

In general, the zooplankton biomass showed higher values during the south-west monsoon season aligned to or closely following the peak period of upwelling. Yearly variations in upwelling is reflected in the plankton production also. The early occurrence of peak abundance of plankton in the southern regions was attributed to the comparatively earlier start of upwelling in the area (Fig.41 and Table-9). Similarly longer period of availability of high plankton biomass in the northern regions could be due to the comparatively longer duration of prolonged upwelling persisting in this area (Fig.42 and Table-9). Moreover higher values of plankton volume in the section off Kasaragod also correspond to the comparatively higher intensity of upwelling observed there (Fig.39).

While it is patently known that the nutrient laden upwelled water triggers the chain of organic production in areas of upwelling, the level of nutrients in the upwelled water in different areas is likely to have a clear influence on the quantum of production and thus on the availability of plankton. Further, the occurrence of good concentration of plankton biomass in an area results in the aggregation of large quantities of plankton-feeding pelagic fishes there, and hence the plankton population is under constant influence of grazing pressure depending on the availability of fish shoals in that area. But some of the earlier workers (Ramamurthy, 1965; Mukundan, 1967; Annigiri, 1969 and Bensam, 1970) pointed out that there is no direct correlation between the plankton density and abundance of plankton-feeding fishes in an area. However in the present study zooplankton indices

FIGURE 41

Distribution of zooplankton biomass (in ml/m^3) interposed with the vertical time section variation of 1 ml O_2/L isoline, (A) off Quilon, (B) off Cochin.

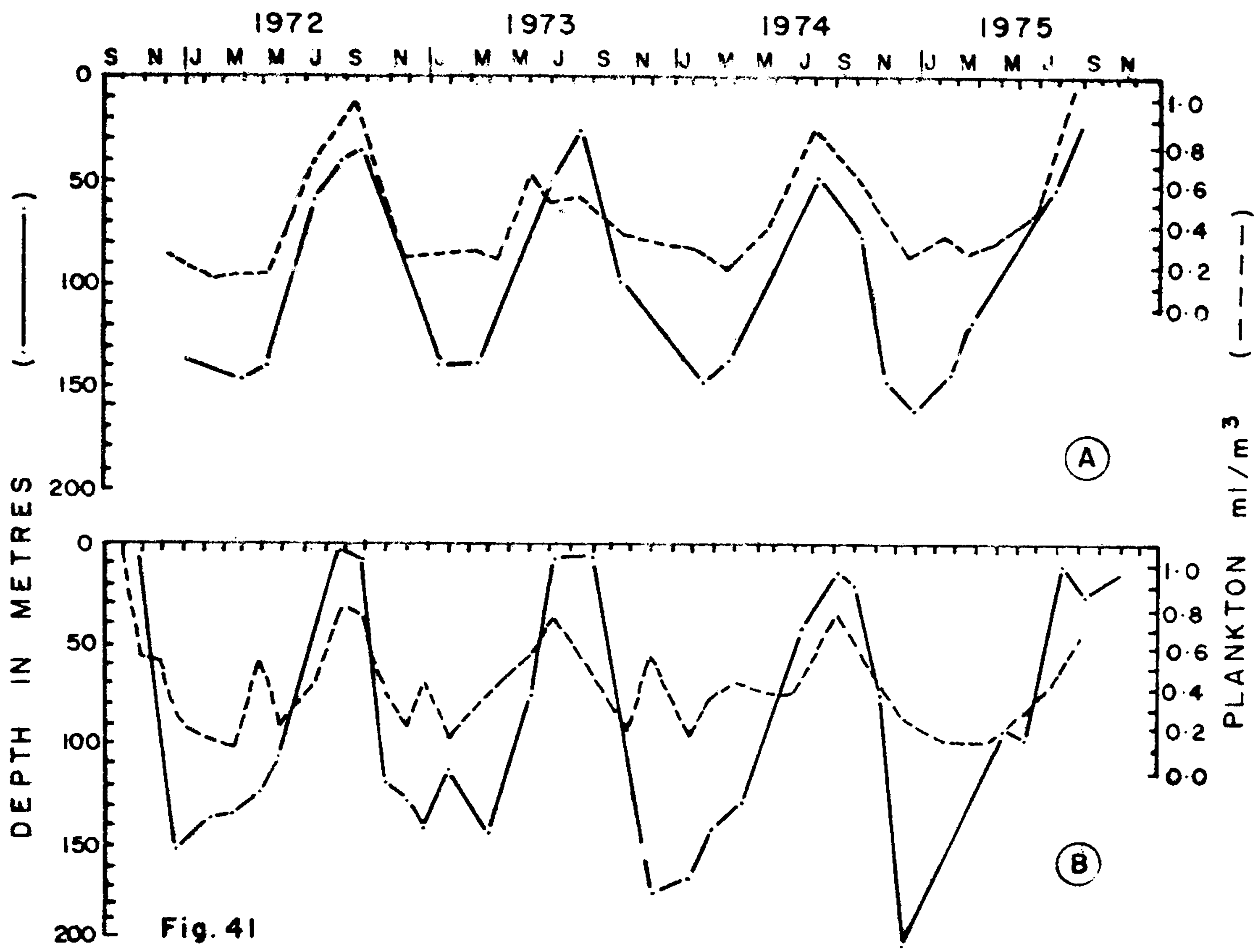

1972
1973
1974
1975
S N J M M J S N J M M J S N J M M J S N J M M J S N
DEPTH IN METRES
PLANKTON ml/m3
A
B

Fig. 41

FIGURE 42

Distribution of zooplankton biomass (in ml/m^3) interposed with the vertical time section variation of the depth of 1 ml O_2/L isoline, (A) off Kasaragod, (B) off Karwar.

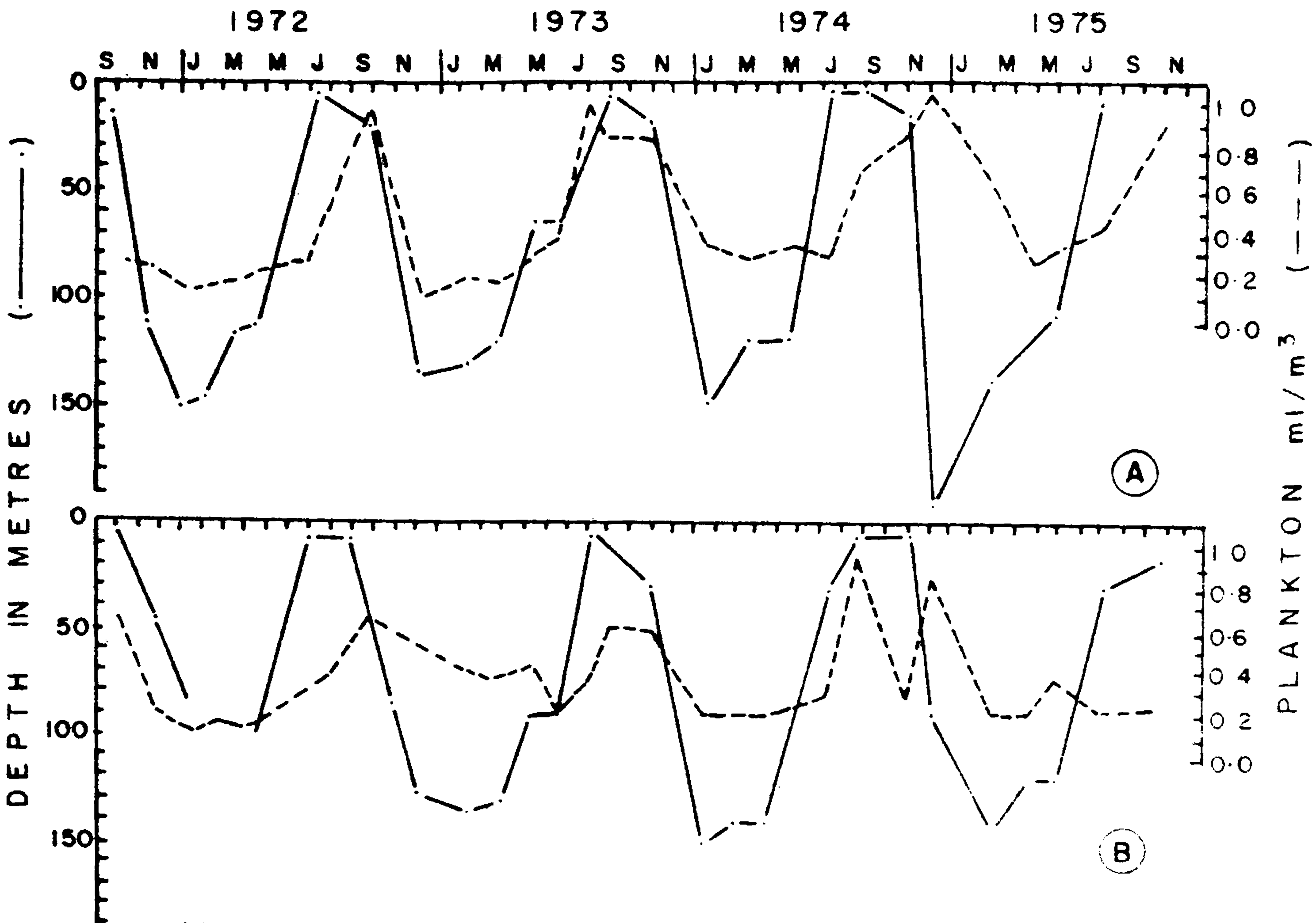

1972
1973
1974
1975
S N J M M J S N J M M J S N J M M J S N J M M J S N
0
50
100
150
200
DEPTH IN METRES
(·———·)
1·0
0·8
0·6
0·4
0·2
0·0
PLANKTON ml/m³
(– – –)
A
B

Fig. 42

at various sections represented by the biomass of the standing crop showed a direct relationship with upwelling.

C H A P E R 7

7 INFLUENCE OF THE HYDROLOGICAL CONDITIONS ON THE PELAGIC FISHERIES OF THE REGION

Oil sardine and mackerel together constitute one of the major pelagic fishery resource of the region under study. The annual average landings along this part of the coast comprising Kerala, Karnataka and Goa for the period from 1971 to 1975 for oil sardine and mackerel were 1,44,691 tonnes and 65,326 tonnes respectively. The fishery season of these species normally starts after the south-west monsoon by August/September. Strong upwelling along the coast brings up nutrient rich sub-surface waters to the surface layers enhancing production at various levels, and finally resulting in the aggregation of large quantities of plankton-feeding pelagic fishes in the areas of its influence. The earlier concept, (Bhimachar and George, 1952) on shoreward migration of these fishes, especially mackerel was that they come to inshore waters for feeding. Banse (1970) reported that the migrations of these fishes are not principally controlled by food and spawning. Though the food of mackerel is plankton only, Ramamurthy (1965) and Mukundan (1967) reported that the abundance of mackerel is not related to the plankton density, directly. Annigiri (1969) observed an inverse relationship between the sardine catch and the volume of plankton. Later, while discussing a sudden decline of oil sardine fishery of 1972 in Kerala, Gopinathan (1974) emphasised the need of studying the vertical circulation for predicting pelagic fisheries in general and oil sardine fishery in particular. During the peak of upwelling season in the inshore waters, only a limited layer at surface contains sufficient oxygen and fish stocks either concentrate at this layer in the form of shoals or migrate to offshore waters. As the upwelling ceases by about September/October the water column gets oxygenated and fishes move to the well mixed inshore waters all along the coast.

Both oil sardine and mackerel undergo large scale horizontal migration. Their movements seem to be closely associated with the shift in the environmental parameters, like, general current pattern along the coast as well as the sequence of upwelling. Chidambaram and Menon (1945) reported that the catches depend upon the amount of rainfall. Pradhan and Reddy (1962), Ramamurthy (1965), Mukundan (1967) and Bensam (1970) stressed the importance of temperature and salinity on the movement of the fish in coastal waters. Murthy and Edelman (1970) observed that certain ranges of monsoon intensity is unfavourable to the oil sardine fishery and certain other ranges favourable. Noble (1972) reported an inverse correlation between the catch of the year and the preceeding monsoon rains. According to Antony Raja (1973) a successful fishery can be predicted from certain ranges of rainfall in the preceeding months. Murty (1974) correlated the wind drift during the winter season of the west coast of India with the oil sardine catches. According to Murty and Vishnudatta (1976) the fisheries of oil sardine and mackerel are associated with high salinity, moderate temperature and deeper thermocline.

Both the species appear first in the southern parts of the Kerala coast during July-August period and gradually advance to northern parts, as the north setting current starts in October. As regards mackerel, Panikkar (1952) stated that it appears first in the south and then slowly extends towards north.

7.1 Seasonal distribution of oil sardine fishery

Oil sardine is a typical shoaling species and the traditional fishery is mainly confined within the 15 km coastal belt with the dense shoals located mostly in the shallow near shore waters. The highest abundance has been noticed off the Kerala and Karnataka coasts, especially between Alleppey-Karwar area (Balan and Raghu, 1979). The oil sardine fishery starts after the commencement of the south-west monsoon and lasts upto about March; September to December being the peak time of occurrence (Jhingran, 1975). The shoaling pattern is found to be associated with the upwelling on the shelf. Once the upwelling ceases by the end of the south-west monsoon, sardines move close to the coast. However, part of the stock remains offshore throughout the year.

Oil sardine landings in 1971-72 season (Anon A, 1973) was 1,75,815 tonnes (Table-10). In this period the fishery lasted up to June at the southern centres of the south-west coast of India and upto March in the northern centres (Figs.43,44 and 45).

Oil sardine fishery showed a single peak in 1971-72 season. The peak period was in November-December in the central regions and further southward, in December-January. At Karwar and Panaji, the fishery lasted only upto December 1971. Kerala coast had maximum landings in 1971-72 season and heaviest catches were between Calicut and Ponnani (Anon A, 1973).

In 1972-73 season, the oil sardine fishery suffered a set back. Combined catches of Kerala and Karnataka was 1,22,825 tonnes which is almost 50,000 tonnes less than the previous season. The decline in the total catch was due to the reduced landings in Kerala coast, while Karnataka recorded almost double the landing compared to the previous season, with the primary peak in November-

December and secondary in April-May (Fig.44).

The combined catches for Kerala and Karnataka for 1973-74 season were observed to be 1,37,755 tonnes. The fishery in Kerala showed maximum in October-December period, with a secondary peak in April-May period. In Karnataka the main fishery took place in January-March period (Fig.44). In 1974-75 season the combined landing was 1,39,924 tonnes. The catches were good for Kerala during the entire fishing season in October-March period, while for Karnataka the main fishery took place in January-March period with comparatively reduced landing than the previous two seasons (Table-10).

The oil sardine landings in Goa was comparatively very poor in all the years (Fig.45). The best catches recorded were 2,077 tonnes in the October-December period of 1972-73 season (Table-10).

7.2 Seasonal distribution of mackerel fishery

Like oil sardine the congregation of mackerel shoals in the surface layers along the coast were most pronounced in the upwelling season. The mackerel shoals were mainly observed in a belt extending along the coast usually between 10 and 25 nautical miles offshore. Usually the mackerel fishery starts in August-September and lasts till March-April with high catches during October-December period. Mackerel shoals were generally most abundant in the area between Cochin-Mangalore. North of Mangalore the fishery starts late in October-November and lasts till February-March (Anon A, 1976). Noble (1979) reported that, though mackerel occurs all along the coast, 90% of the catches are from the west coast off Quilon-Ratnagiri region. The total mackerel landing in Kerala and Karnataka for the 1971-72 season (Anon A, 1973) was 1,00,599 tonnes (Table-11). In the northern most centres, the fishery season commences during October and lasted upto March, while in the central region from Malpe to Ponnani the fishery lasted upto June. The monthly data showed that November-December period was generally the months of peak abundance in most of the centres (Anon A, 1973). In 1972-73 season the mackerel landings were very poor in all the centres. Total landings in Kerala and Karnataka were 26,742 tonnes. The peak of abundance appeared slightly earlier than the previous seasons (Figs.43 and 44). Comparatively better landings (4,577 tonnes) were recorded in Goa, than the other regions, during this season (Table-11). The mackerel landings of 1973-74 season for the Kerala and Karnataka coasts were 60,988 tonnes and the estimated landing at Karwar alone made up to 31.8% of the total

(Anon A, 1976). The peak landings occurred during October-December period in the Kerala and Karnataka coasts and January-March period in Goa. The mackerel landing of Kerala and Karnataka coast again dropped down considerably in 1974-75 season from the previous season to 22,074 tonnes. This was the lowest landings recorded in these areas for the whole period of 1972-75. The low values are the result of the reduced landings in Karnataka and Goa. The peak landing occurred earlier in Kerala coasts than further north (Figs 43, 44 and 45).

7.3 Influence of temperature and salinity on oil sardine and mackerel fisheries

Temperature and salinity values of different ranges corresponding to the period of occurrence of good catches of oil sardine and mackerel were reported based on the observations at various places along the west coast of India by Sekharan (1962), Pradhan and Reddy (1962), Sekharan and Dhulkhed (1963), Ramamurthy (1965), Annigiri (1969), Bensam (1970), Prabhu and Dhulkhed (1970), Prabhu (1971), Venkitaraman and Rao (1973) and Gopinathan (1974). The mackerel schools were to a great extent distributed in the same area as the oil sardine schools, and they were often difficult to distinguish from one another (Anon A, 1976). Hence the temperature and salinity conditions prevailing in the coastal waters within 15 nautical miles from the shore in the different sections worked off Kerala, Karnataka and Goa coasts were correlated with the distribution of both oil sardine and mackerel. The diagram thus presented (Figs.43,44 and 45) revealed the following relations:

Majority of the good catches were recorded in a period when temperature conditions of the corresponding localities were between 27.00 - 29.50°C which may be the optimum temperature range. The catches showed decrease with the increase of temperature from March onwards. The temperature dropped considerably during June-August period near to the coastal waters with a wider range (21.00 - 27.00°C) followed by very low catches of oil sardine and mackerel. Again, by the start of fishery season in August-September period, the temperature gradually increased at all depths and at the time of peak landings it was observed that the temperature conditions were within the above mentioned optimum range. Thus it was observed that the catches were decreasing with increase of temperature in the hot weather season and attained the minimum mark by the onset of the south-west monsoon, when considerably low temperature conditions prevailed along the coastal waters.

As regards salinity, maximum catches were recorded from areas when the salinity of the water column varied between 33.50 - 35.00‰. The salinity conditions were found to have a major influence on the availability of these fishes rather than temperature. It is evident that (Figs.44B and 45B) the decrease of fishery towards north, were due to the higher salinity conditions (greater than 35.5‰) prevailing in these areas during most part of the year. Moreover the duration of occurrence of optimum range of salinity was also found to be shorter in the northern sections than south of it. Thus even with the optimum range of temperature conditions at times the fishery in the northern region was found to be comparatively poor, probably due to the influence of the higher salinity water. This was well reflected in the catch data for Kerala, Karnataka and Goa (Tables-10 and 11 - Figs.43,44 and 45).

Mackerel seems to have a better tolerance of a higher range of salinity beyond the above mentioned ranges. The peak period of mackerel landings at times coincided with higher salinity and lower temperature conditions in the coastal waters. Comparatively higher catches in certain years (Table-11) could be attributed to the longer period of occurrence of favourable environmental conditions in the traditional fishing zones of certain localities.

A perusal of the catch data for oil sardine and mackerel and the temperature and salinity conditions prevailing in the coastal waters within 15 nautical miles from the shore further confirmed that the catches were generally poor when there was considerable variation in the temperature and salinity values beyond the above mentioned ranges.

The oil sardine landings were found to be maximum in the Kerala coast (Table-10), where comparatively wider range of salinity and temperature prevailed (Figs.43A and B). This was due to the influence of the lower salinity equatorial surface water prevailing during most part of the fishing season as well as on account of more intense upwelling which brought up higher salinity water.

The oil sardine appears to have better tolerance of the lower salinity equatorial surface waters present along the Kerala coast during October-January period and are found to be avoiding areas of Arabian sea water of higher salinity of the northern areas. The fishery season for both the species comes to an end by about April, when the surface layer temperature rises to above 30.00°C and southerly current brings down higher salinity Arabian sea water to the shelf waters of the south-west coast of India. This could perhaps be the reason for the decrease of oil sardine fishery relatively earlier in the

Table-10 Seasonal landing of oil sardine in Kerala, Karnataka and Goa during 1971-72, 1972-73, 1973-74 and 1974-75 (in tonnes).

Year	Period	Kerala	Karnataka	Goa	Total
1971	Jul.-Sep.	19,371	46	24	19,441
	Oct.-Dec.	82,064	3,897	1,919	87,880
1972	Jan.-Mar.	40,526	4,824	1,274	46,624
	Apr.-Jun.	21,564	235	71	21,870
Total for 1971-72		163,525	9,002	3,288	175,815
1972	Jul.-Sep.	11,709	353	371	12,433
	Oct.-Dec.	30,199	10,199	2,077	42,475
1973	Jan.-Mar.	35,966	7,113	-	43,079
	Apr.-Jun.	580	26,734	-	27,314
Total for 1972-73		78,454	44,399	2,448	125,301
1973	Jul.-Sep.	18,963	258	653	19,874
	Oct.-Dec.	55,285	7,619	964	63,868
1974	Jan.-Mar.	18,594	14,305	-	32,899
	Apr.-Jun.	20,623	488	-	21,111
Total for 1973-74		113,465	22,670	1,617	137,752
1974	Jul.-Sep.	15,269	579	-	15,848
	Oct.-Dec.	47,649	5,412	204	53,625
1975	Jan.-Mar.	44,877	9,567	972	55,416
	Apr.-Jun.	14,833	474	88	15,395
Total for 1974-75		122,628	16,032	1,264	139,924

Table-11 Seasonal landing of mackerel in Kerala, Karnataka and Goa during 1971-72, 1972-73, 1973-74 and 1974-75 (in tonnes).

Year	Period	Kerala	Karnataka	Goa	Total
1971	Jul.-Sep.	719	775	18	1,512
	Oct.-Dec.	10,956	35,636	30,886	77,478
1972	Jan.-Mar.	16,655	25,632	14,097	56,384
	Apr.-Jun.	8,602	1,624	18	10,244
Total for 1971-72		36,932	63,667	45,019	145,618
1972	Jul.-Sep.	5,016	1,547	1,307	7,870
	Oct.-Dec.	4,171	3,446	4,577	12,194
1973	Jan.-Mar.	4,642	2,142	-	6,784
	Apr.-Jun.	1,052	4,726	-	5,778
Total for 1972-73		14,881	11,861	5,884	32,626
1973	Jul.-Sep.	6,657	289	225	7,171
	Oct.-Dec.	7,038	29,091	7,356	43,415
1974	Jan.-Mar.	2,285	6,415	487	9,187
	Apr.-Jun.	319	896	-	1,215
Total for 1973-74		16,299	36,621	8,068	60,988
1974	Jul.-Sep.	2,368	1,130	294	3,792
	Oct.-Dec.	5,363	1,255	293	6,911
1975	Jan.-Mar.	5,513	1,873	66	7,452
	Apr.-Jun.	3,773	138	8	3,919
Total for 1974-75		17,017	4,396	661	22,074

FIGURE 43

Seasonal landings of oil sardine and mackerel in Kerala coast during 1972-75 period and mean monthly ranges of temperature (A) and salinity (B) prevailing within the coastal waters of the region.

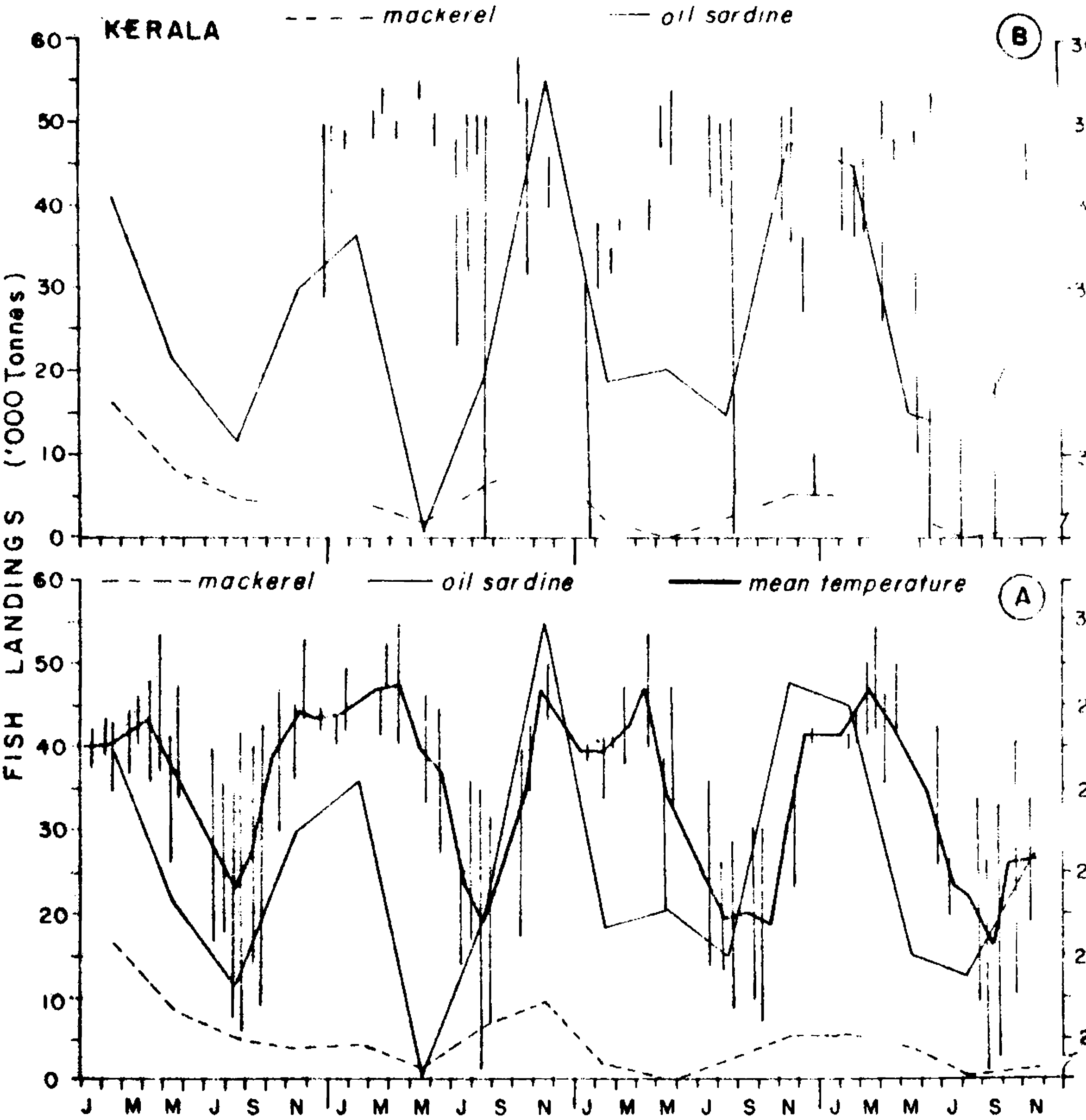
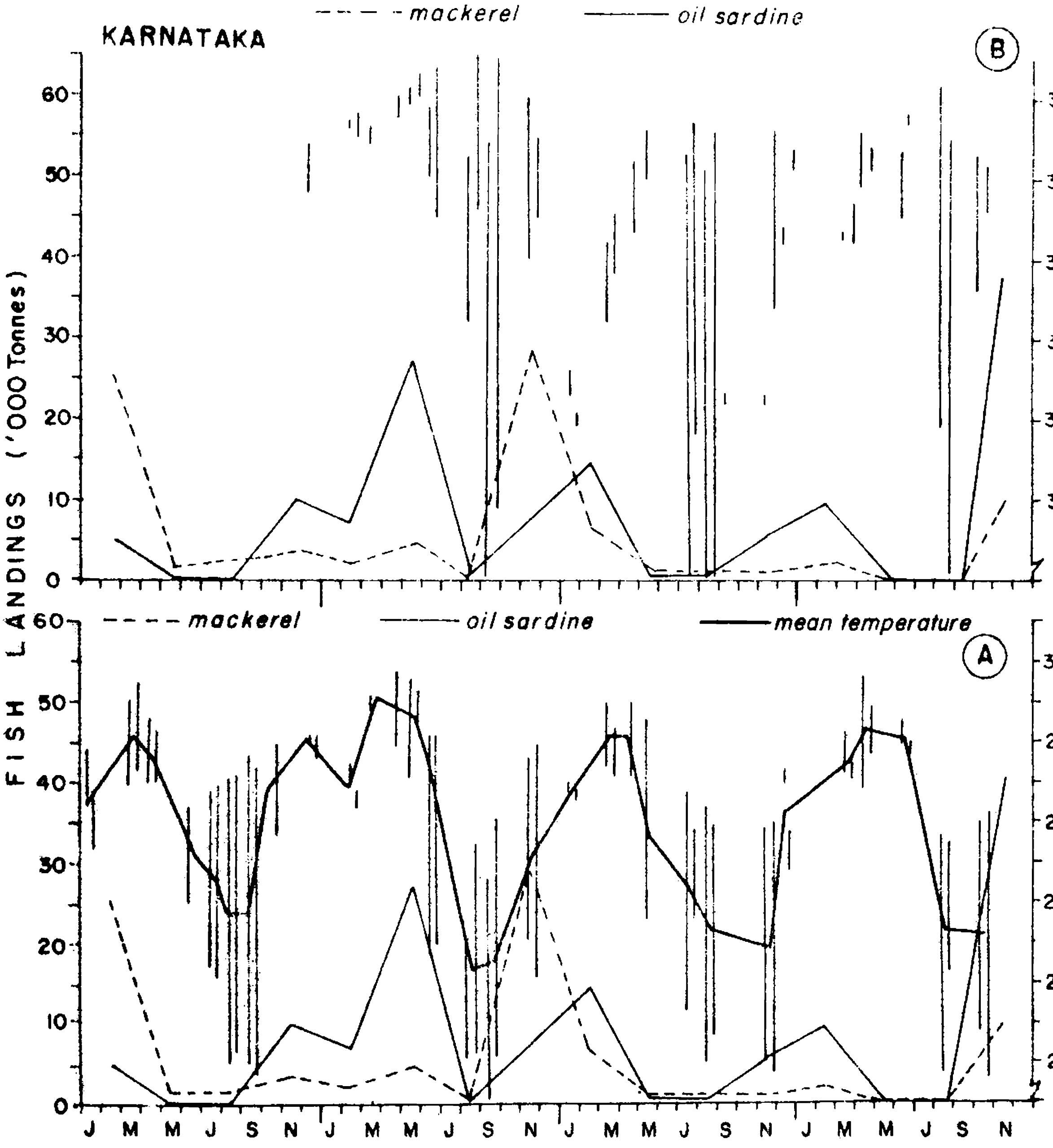

KERALA
mackerel
oil sardine
B
36
35
31
SALIN.
60
50
40
30
20
10
0
FISH LANDINGS ('000 Tonnes)
mackerel
oil sardine
mean temperature
A
31
29
27
25
23
21
TEMPERATURE (°C)
J M M J S N J M M J S N J M M J S N J M M J S N
1972
1973
1974
1975

Fig.43

FIGURE 44

Seasonal landings of oil sardine and mackerel in Karnataka coast during 1972-75 period and mean monthly ranges of temperature (A) and salinity (B) prevailing within the coastal waters of the region.



KARNATAKA
mackerel
oil sardine
B
A
mean temperature
FISH LANDINGS ('000 Tonnes)
SALINITY (‰)
TEMPERATURE (°C)
J M M J S N J M M J S N J M M J S N J M M J S N
1972
1973
1974
1975

Fig.44

FIGURE 45

Seasonal landings of oil sardine and mackerel in Goa coast during 1972-75 period and mean monthly ranges of temperature (A) and salinity (B) prevailing within the coastal waters of the region.

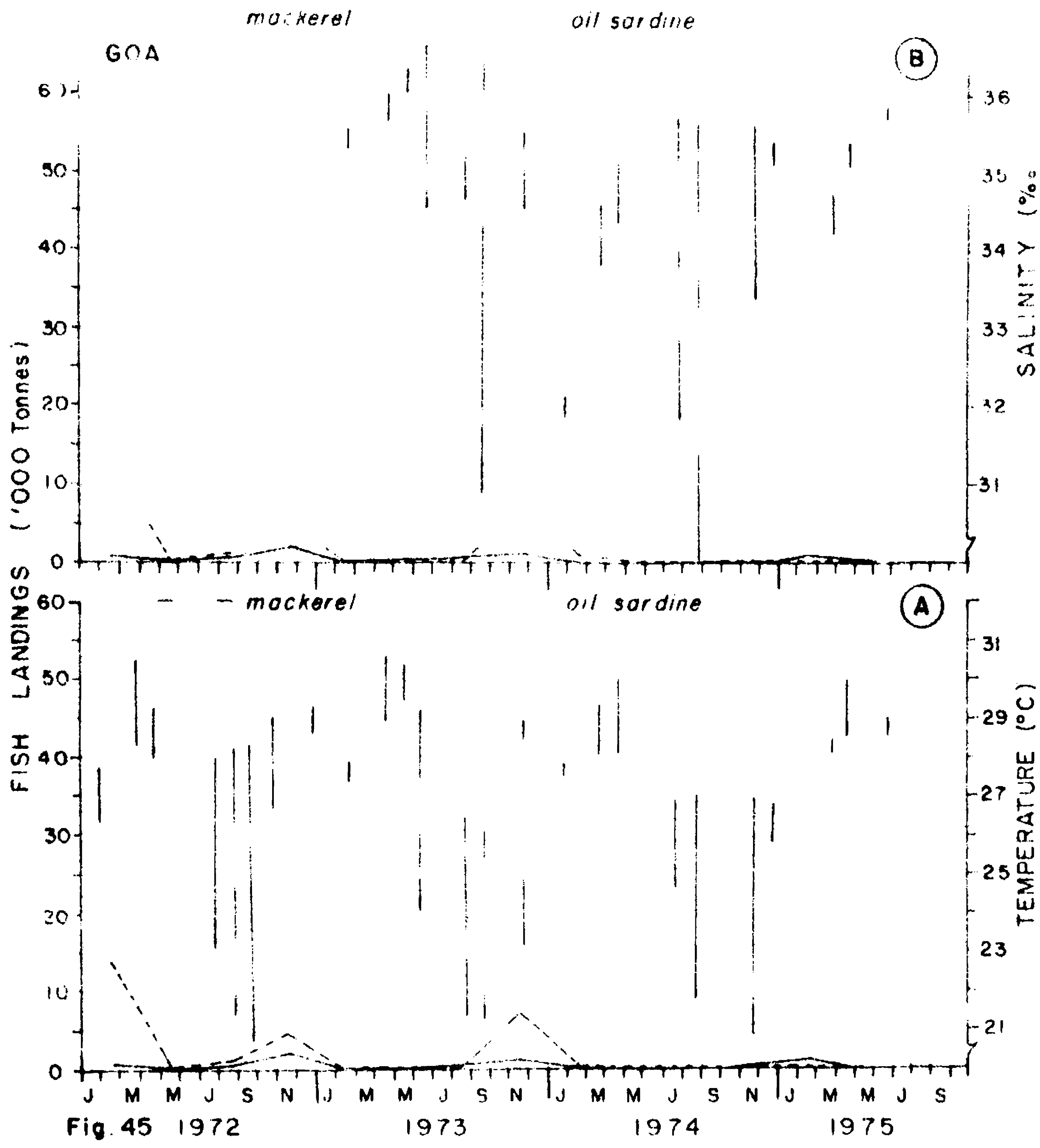

GOA
mackerel
oil sardine
B
A
FISH LANDINGS ('000 Tonnes)
SALINITY (‰)
TEMPERATURE (°C)
J M M J S N J M M J S N J M M J S N J M M J S
1972 1973 1974 1975

Fig. 45

northern region as observed by Chidambaram (1950) and Antony Raja (1969). Both the species then migrate to offshore waters to favourable environmental conditions. Recently with the introduction of purse-seine, Balan and Raghu (1979) reported that the fishery for oil sardine is extended to slightly deeper waters even up to June.

Basically, the earlier start of upwelling in the southern region increases the productivity of the region. The south-west monsoon rains and river run off lower the salinity of the upwelled low temperature waters and thus provide suitable environment for the earlier start of the fishery in the southern region. Very low temperature, higher salinity and low oxygen values at subsurface layers force the fishes to concentrate at surface layers only for a certain period, until stratification of layers take place by the monsoon rains and river run off. As the upwelling proceeds northwards followed by monsoon rains, the fishery and the fishing intensity all along the coast also advances, depending on the intensity and duration of upwelling and the monsoon rains. Considerable fluctuations in the fishery also take place every year depending upon the occurrence of favourable environmental factors.

CHAPTER 8

8 SUMMARY

The objective of the present study was to elucidate the hydrological conditions of the shelf waters along the southern half of the west coast of India and their relation to the zooplankton biomass and pelagic fish resources.

Data from six hydrography-plankton sections worked during the 1972-75 period off Cape Comorin, Quilon, Cochin, Kasaragod, Karwar and Ratnagiri formed the basis of the present study. Stations were fixed along the transects, 10 nautical miles apart, starting with the first station at around 15 metre depth and were usually occupied 5 to 8 times in an year at an interval of about 6 weeks. Data relating to oil sardine and mackerel fisheries were availed from published information relating to the period, mainly of the Central Marine Fisheries Research Institute.

The ranges of different parameters namely temperature, salinity, density and dissolved oxygen at different depths and their sloping features against the coast are discussed. Three seasons, namely south-west monsoon (summer monsoon), north-east monsoon (winter monsoon) and hot weather season are designated and data of the core months of each of these seasons considered in the study.

The vertical sections of temperature, salinity, density and dissolved oxygen in the transects studied revealed the presence of cool, dense, high saline and less oxygenated upwelled water at different depths during the various seasons. In general, the mixed layer extended to about 35 metres depth during the south-west monsoon season and to about 75 metres during the north-east monsoon. In both the seasons it was shallowest in the section off Kasaragod.

Usually the surface and subsurface waters of the shelf showed lowest temperature during the south-west monsoon along the entire region. The temperature was moderate during the north-east monsoon and highest during the hot weather season. The upsloping of the low temperature subsurface waters was more pronounced during the south-west monsoon period.

During the hot weather season, comparatively warmer water was observed in the Kasaragod - Karwar region where temperature values above 29.00°C were recorded at all depths within the upper 20 metre depth column. Generally, low values were observed at the surface layers in all the sections in the south-west monsoon period with the lowest values being observed in the coastal stations off Kasaragod. During the north-east monsoon, Quilon - Kasaragod region showed higher temperature (above 28.00°C) in the upper 30 metre depth column with temperature values decreasing on either side.

The salinity did not show much variation between the southern and the northern areas. However, during the north-east monsoon period the salinity in the northern area showed slightly higher values. In the neritic waters certain pockets in the southern region showed lower salinity during the south-west monsoon.

In the entire shelf waters, the salinity variations were more during the south-west monsoon period and they were of higher range during the hot weather season.

During the south-west monsoon period the surface values of dissolved oxygen were very high. However, at depths below 50 metres, dissolved oxygen values were less than 1 ml/L. The range of dissolved oxygen values in the water column appeared to be least during the north-east monsoon period off Kasaragod and southwards. On an average, the dissolved oxygen values were above 4 ml/L during this period.

The areas of upwelling were identified along the coast, by two different methods, namely mean rate of fall of temperature (°C per week) within the shelf, as well as by the mean rate of ascent of 1 ml/L dissolved oxygen layer (m/week). Both the indices gave almost identical results, indicating that the region off Kasaragod was the area of most intense upwelling with the intensity decreasing on either side.

The process of upwelling commenced at deeper layers around 150 metres by about February in the Quilon - Kasaragod region. The start of upwelling was observed to be delayed towards north, in the Karwar and Ratnagiri sections. While upwelling ceased earlier by about September in the southern sections in the Northern areas upwelled water remained at surface upto October and even November in certain years. Year to year variations were observed in the duration and intensity of upwelling.

In 1972, the intensity of upwelling (measured by the average rate of fall of temperature °C per week) was more in the Karwar section (0.42°C/week) and low off Ratnagiri (0.24°C). Upwelled water remained for maximum duration at surface off Kasaragod.

In 1973, intensity was more in the Kasaragod section, but relatively low on either side of its. Upwelled water remained at surface for longer periods off Kasaragod and Karwar.

In 1974, intensity and duration of upwelling were maximum off Kasaragod, while in 1975, upwelling was generally weak all along the south-west coast compared to previous years.

In the northern areas unstable conditions were observed in the upper layers during most part of the year. This may be attributed to the absence of strong vertical thermal gradient as well as the absence of low salinity water. However, the mean value of stability for the hot weather monsoon, the south-west monsoon season and the north-east monsoon, showed that the upper column of water (20 metres) was relatively stable than the lower column (50 - 100 metres) in the southern sections, while the reverse was the case in the north. The season to season variations of stability, however, did not show any systematic trend of change.

Generally low values of zooplankton biomass have been observed in January-March period. Increase in biomass was noticed from April onwards with the peak in July-September period.

Peak of plankton production was attained earlier in the southern area and later in the north, in sequence to the earlier upwelling in the south and its later occurrence in the north. The longer period of availability of high plankton biomass observed in the northern area may be attributed to the longer duration of upwelling there. Similarly, the higher plankton biomass observed off Kasaragod may be due to the higher intensity of upwelling noticed in this area.

The 27.00°C - 29.50°C temperature range was found to be optimal for good catches of oil sardine and mackerel. Catches showed decrease with increase of temperature from March onwards.

Likewise the salinity range from 33.50 - 35.00‰ was found to be optimal for good catches of both the species. The decrease of these pelagic fisheries in the north coincides with the increase of salinity conditions in the region due to the influence of high saline Arabian sea water.

The duration of occurrence of optimum range of salinity was shorter in the northern area and the fishery season for the species also found shorter. However, mackerel is observed to have a better tolerance of a higher range of salinity, while the oil sardine appeared to tolerate comparatively lower salinities.

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