STUDIES ON THE SURFACE MIXED LAYER AND ITS ASSOCIATED THERMOCLINE OFF THE WEST COAST OF INDIA AND THE INFERENCES THEREBY FOR WORKING OUT A PREDICTION SYSTEM OF THE PELAGIC FISHERIES OF THE REGION

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Part-A

Introduction

The thermocline in the sea, which separates the warm mixed layer at the top and the cold stratified layers below, is important from many aspects. The greater the depth of the thermocline the more will be the water column of the mixed layer enriched with dissolved oxygen which will be available for sea life. The vertical distribution of nutrient salts depends upon the situation of the thermocline (Graham, 1954). The depth of the pelagic shoals depends largely on the vertical extension of the mixed surface layer (Hela and Laevastu, 1962). The vertical extent of the mixed surface layer is also important from the view point of the vertical distributions of the buoyantly floating eggs and larvae of the pelagic fish which are affected by the vertical turbulence occurring in the layer (King and Hide, 1957; Silliman 1950).

The distributions of the depths of mixed layer were theoretically computed from wind distributions over the sea and were presented in charts by Lumby (1955). Duncan (1964) studied various aspects of the thermocline occurring off the south west coast of Africa by frequently and systematically taking observations from a network of stations.

The depth of occurrence of thermocline at different times and regions of the Indian seas were referred to by various authors (C. S. I.R.O. Australia, 1962; Edelman, 1960; Jayaraman *et al.* 1960; Orren, 1963; Patil and Ramamirtham, 1963; Patil *et al.* 1964; Rao, 1959; Ramamirtham and Jayaraman, 1960; Ramasastry and Myrland, 1959; Robinson, 1964; Sewell, 1932). Most of these results were limited to the individual cruises without repeating observations from the network of stations. The effect of internal waves (La Fond, 1962) would no doubt be considerable on such data, although it cannot be quantitatively expressed. This effect would be minimised if analyses are made based on averaged data which are possible only when stations are occupied a number of times.

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Sewell (1932) discussed the seasonal changes in position and extent of the 'discontinuity zone' in the Bay of Bengal.

The study of the characteristics of the thermocline in the region off the west coast of India (between Cape Comorin and Mangalore) is taken up in the present analysis. The oceanographic data collected on board the 'KALAVA' and R. V. 'VARUNA' from 1957 to 1964 have been utilised here.

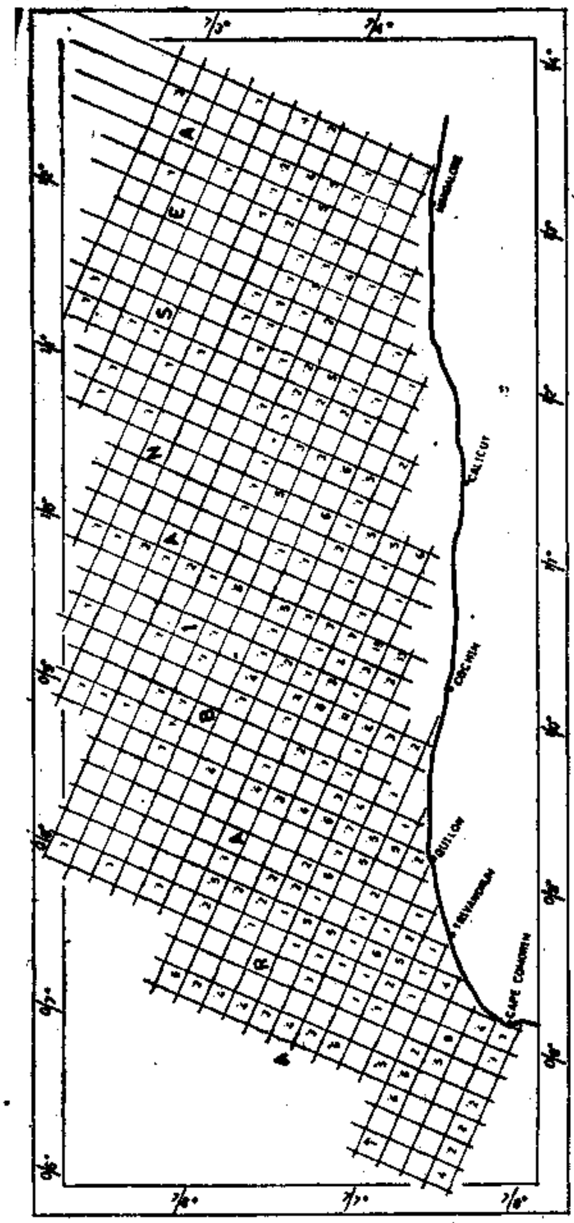

FIG. 1 The distribution of observations in the area

ANALYSIS

The region under investigation is divided into squares of ten sea-miles. The squares that are visited for observations are shown in Fig. 1. The number marked in each cell (square) refers to the frequency of observations made during the above mentioned period. A few more stations (not shown in the figure) which are located slightly beyond the area are also taken into consideration in the present analysis.

The mean values of some interesting physical parameters in each square have been obtained for different seasons of the year. The year is divided into three seasons, *i.e.*, the monsoon (June to September), the winter (November to February) and the summer or the hot weather season or the spring (March to May). The month of October has been treated as a transition period from the monsoon season to the winter season.

The depth of the top of the thermocline, or the depth of vertical extent of the surface 'mixed' layer having a temperature discontinuity layer below it, has been obtained either from bathythermograms or from hydrographic cast at each station. In the hydrographic cast, the temperature data from different International, standard depths of the station are set on a simple 'slide system' devised by the author. A hair-thin nylon thread is carried through the pin-holes of 'slides' which are set at intervals of space, linearly corresponding to the depths of observations. The slides can be moved along their axes which are parallel to the temperature axis. The nylon thread, on the background of a calibrated centimeter graph sheet, in its set position represents the vertical profile of temperature on a linear scale. With the aid of this simple device, temperatures are read as accurately as 0.05°C and the depth scale permits reading small depths as low as 0.5 m.

RESULTS AND DISCUSSION

(a) *Depths of the top of thermocline*—The variations of the depth of the top of thermocline or the depth of the vertical extent of the mixed layer from the surface having a temperature discontinuity layer below it are shown in Fig 2a, b, c for the three different seasons of the year. The bottom contours of the region are shown in Fig. 3 for comparative study. In general, shallow depths of the discontinuity layers are situated close to the shore indicating the effect of the shallow bottom upon the thermocline position.

Sewell's data (Sewell, 1932) were rather inadequate to draw reliable conclusions regarding the seasonal changes of the depth of the discontinuity zone. Nevertheless, it appeared probable that the variation of the depth of the discontinuity zone exhibits two maxima during the year, which occur almost at the same depth during the peak periods (July and January) of the two monsoons. It also appeared probable that the discontinuity zone almost reaches the surface during March-April.

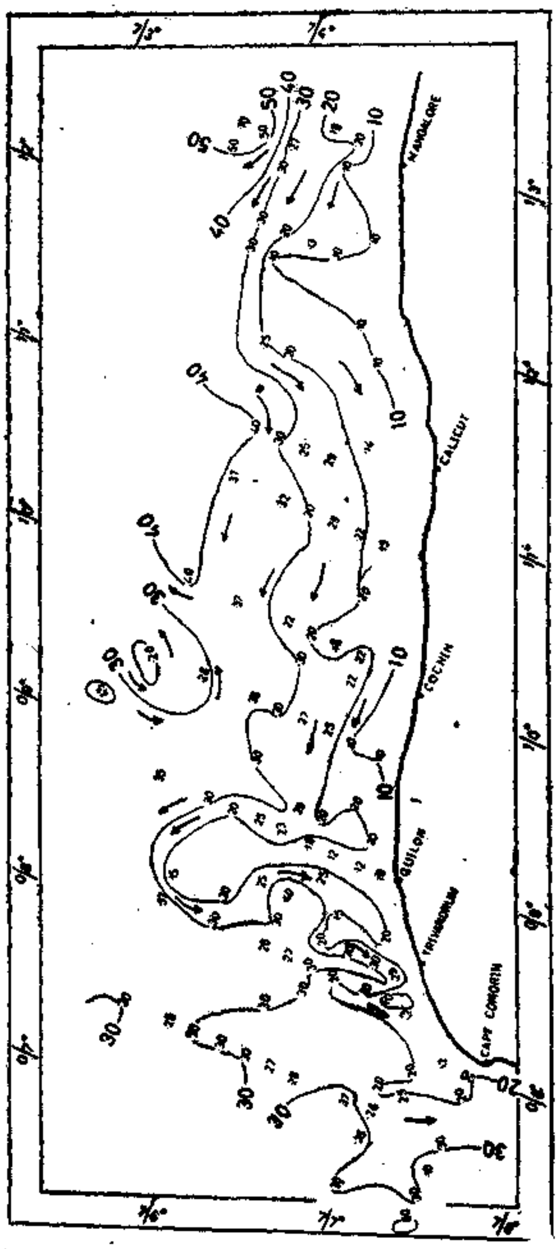

FIG. 2a The distribution of thermocline depth (m) during (Monsoon season)

FIG. 2b The distribution of thermocline depth (m) during (Winter season)

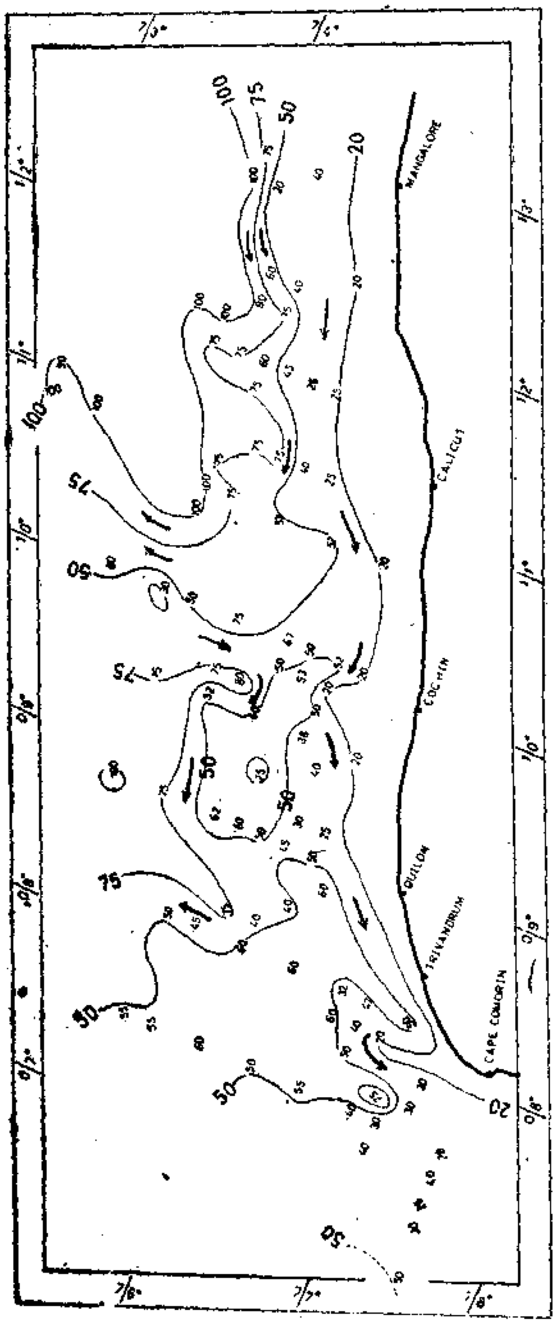

FIG. 2c The distribution of thermocline depth (m) during summer season

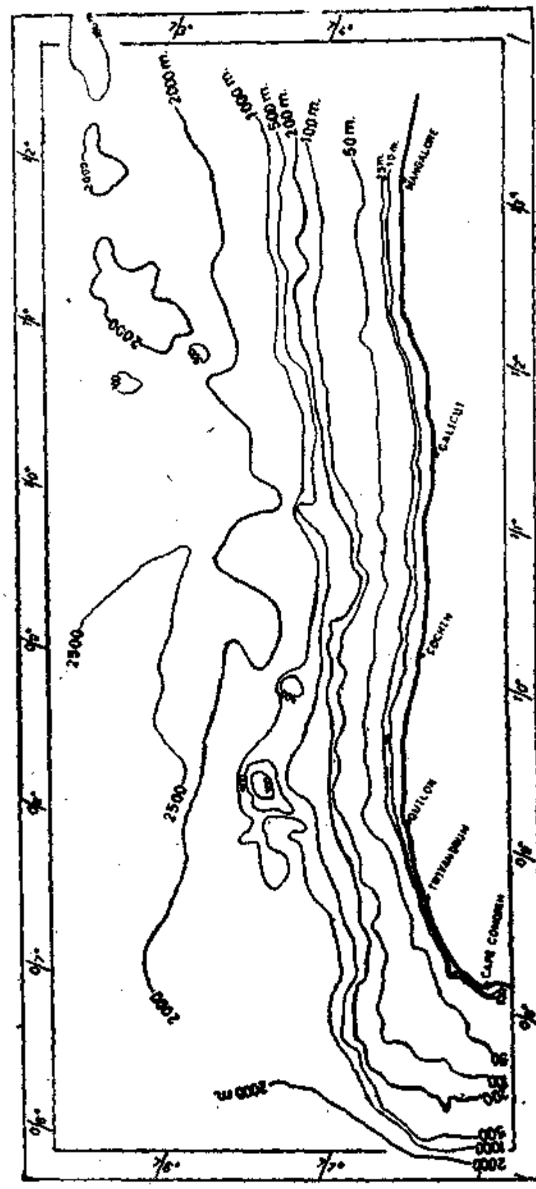

FIG. 3 The bottom topography

Duncan's observations (Duncan, 1964) off the south-west coast of Africa showed that the thermocline is shallow during the (Southern) summer, deep during the spring and deepest during the winter.

The present analysis (Fig. 2a, b, c) reveals that on an average over the region of investigation, the thermocline depths are low during the monsoon, moderate during the summer and great during the winter. Though winds are usually strong during summer and monsoon, the mixed layer extends only to relatively shallow depths. During winter, the surface water temperatures are low. Moreover, the evaporation from the sea surface is more during winter as the atmosphere above it would be less humid. In addition, dilution of the surface waters is minimum during winter as the rains and river discharge would be considerably less during this season. Consequently, the surface waters will have higher densities than the lower layers. Mixing due to instability, therefore, takes place down to considerable depths from the surface. Thus, the thermocline during winter does not necessarily form in the shallow waters, and is noticed farther away from the coast where the bottom depth is sufficiently great to allow the deep formation of thermocline.

During the monsoon, the depths of the top of thermocline range from about 10 to 30 m. in the southern half of the region and from about 10 to 40 m. in the northern half. The depths increase away from the shore. The gradients of thermocline depths are rapid in the south western part and the northern-most corner of the region.

The winter thermoclines which are established further off-shore have their depth-gradients much stronger. The hundred-meter depth line of thermocline runs from south to north almost close to the shelf-edge. The depths decrease on both sides of this line. In the south-western part of the region the depths of thermocline again increase on the seaward side, whereas in the southern and northern corners the depths beyond the 100 m. depth-line decrease.

The discontinuity layer gradually appears towards the shore from the shelf-edge as time advances from winter to summer and the depths of thermocline are shortened. The 100-m depth line of thermocline is now pushed, away from the shelf-edge and is limited only to the northern part of the region. The 20 m. depth line runs in the coastal waters with continuity from south to north. A closed line of 50-m. depth is situated away from the shelf in the central part. The depths slope up towards the coast in the whole region and their gradients are intensified in the northern region. There are negligible gradients in the south-western region. During this season, the depths range from 20 to 60 m. in the southern and the south-western parts, 20 to 80 m. in the central part and 20 to 100 m in the northern part of the region.

(b) *The distribution of temperature at the top of the thermocline*—The temperature distribution associated with the top-depth of thermocline are shown in Fig. 4a, b, c for different seasons.

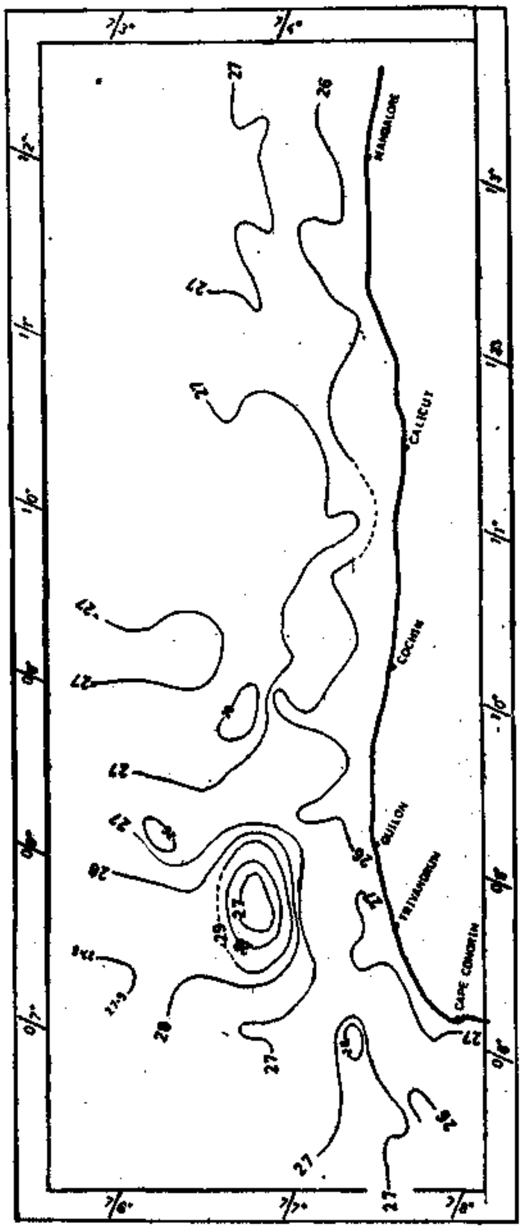

FIG. 4a The distribution of temperature (°C) (Monsoon season)

FIG. 4b The distribution of temperature (°C) (Winter season)

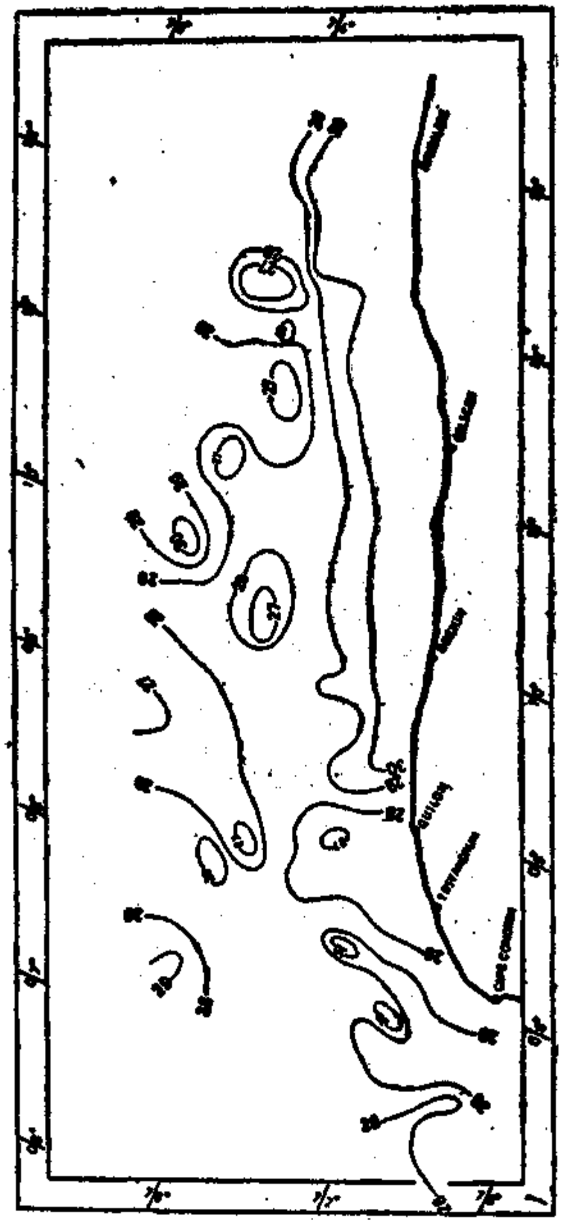

FIG. 4c The distribution of temperature (°C) (Summer season)

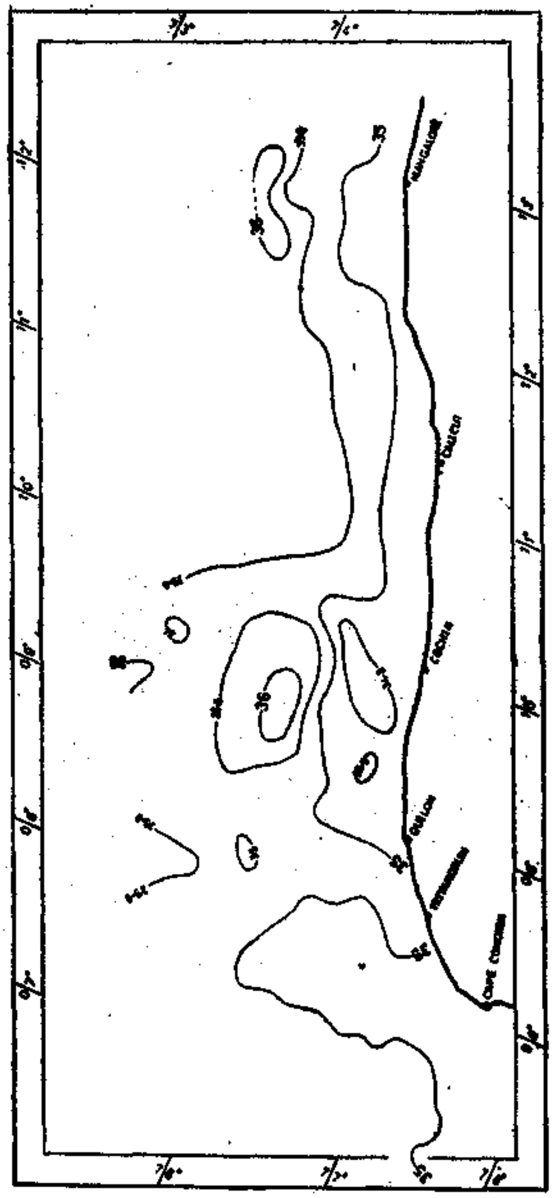

FIG. 5a The distribution of salinity (°/₀₀) (Monsoon season)

The temperature at the top of the thermocline depths ranges from 26° to 29°C during the monsoon season and the range is slightly less during the winter and slightly more during the summer season.

During the monsoon season the surface of the thermocline depth has a lower temperature on the coast-side than offshore. A warm region is situated in the southwestern region (off Quilon) during this season and here the thermal gradients along the thermocline depth surface are more. The warm region is shifted towards north (off Ponnani) during the winter season and the southern zone has lower gradients. During summer, the isotherms are fragmented into a number of small cells offshore. During this season higher temperatures are in the coastal region than offshore unlike the monsoon conditions.

(c) *The distribution of salinity at the top of the thermocline*—The distribution of salinity associated with the depth of the top of thermocline in the region are shown in Fig. 5a, b, c for different seasons of the year.

The salinity ranges from about 34.5% to 36.0% during the monsoon, 35.0% to 36.0% during the winter and 34% to 36% during the summer.

Maximum salinity (about 36%) is confined to two small zones (off Cochin-Quilon and off Mangalore) during the monsoon season. The salinity pocket off Cochin-Quilon is pushed further away from the coast during winter and the northern pocket of salinity spreads over a wider area by this season. The Cochin-Quilon pocket of maximum salinity disappears by summer and the high salinity region of the north shrinks back confining itself to a narrow region.

(d) *The intensity of temperature fall in the transitional layer of the thermocline*—The variations in the depth-rate of temperature fall in the discontinuity layer with varying distance from the coast along different parallels in the different seasons are shown in Fig. 6. It is evident from the figure that no relevant variation during any season, in the gradient of thermocline occurs as one passes from the shore water to the far off along the parallel at each place. It also appears that the gradient of temperature is not much dependent upon the latitude of the place, at least within the region of investigation.

However, a seasonal change in the thermocline intensity may be observed from the figure. The gradients along the parallels are the lowest (1.16°C/10m) during the summer, moderate (1.32°C/10m) during the winter and highest (1.95°C/10m) during the monsoon season. The mean intensities of temperature-fall in the discontinuity layer over the entire region are 1.29°C/10m, 1.54°C/10m and 1.99°C/10m in the respective seasons.

(e) *The system of currents*—Currents may be set up due to the sloping thermocline depth surface. It is difficult to say which is the cause and which is the effect of these two. Perhaps, the slope of the thermocline depth-surface and the

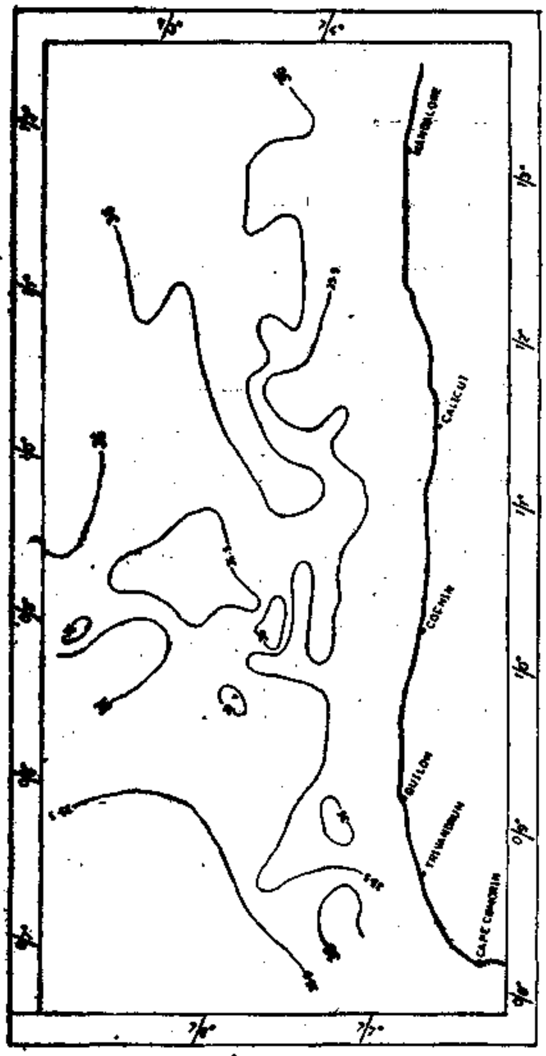

FIG. 5b The distribution of salinity (°/oo) (Winter season)

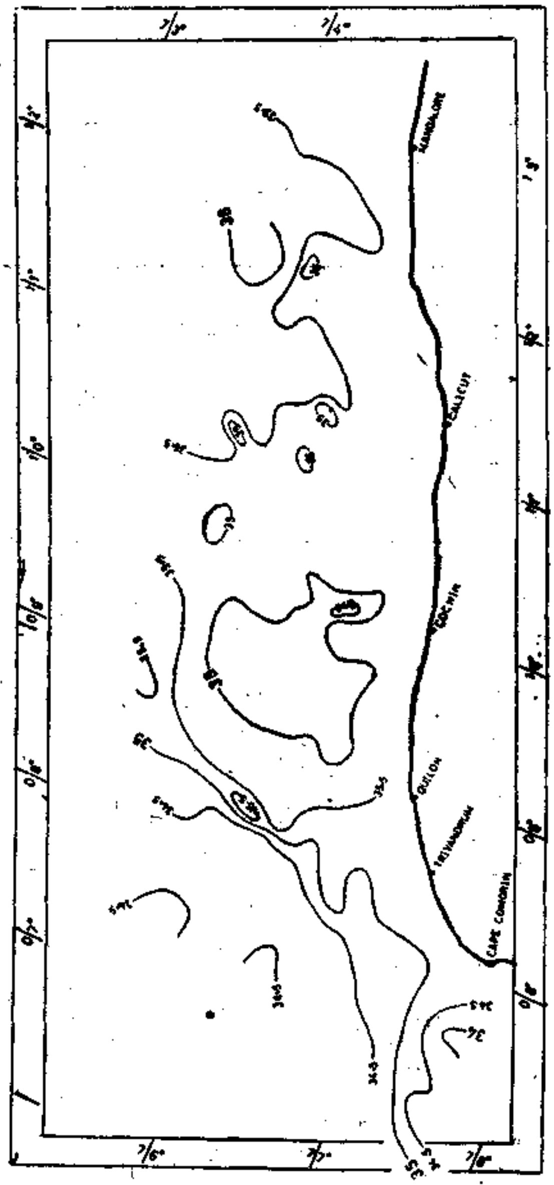

FIG. 5c The distribution of salinity (°/oo) (Summer season)

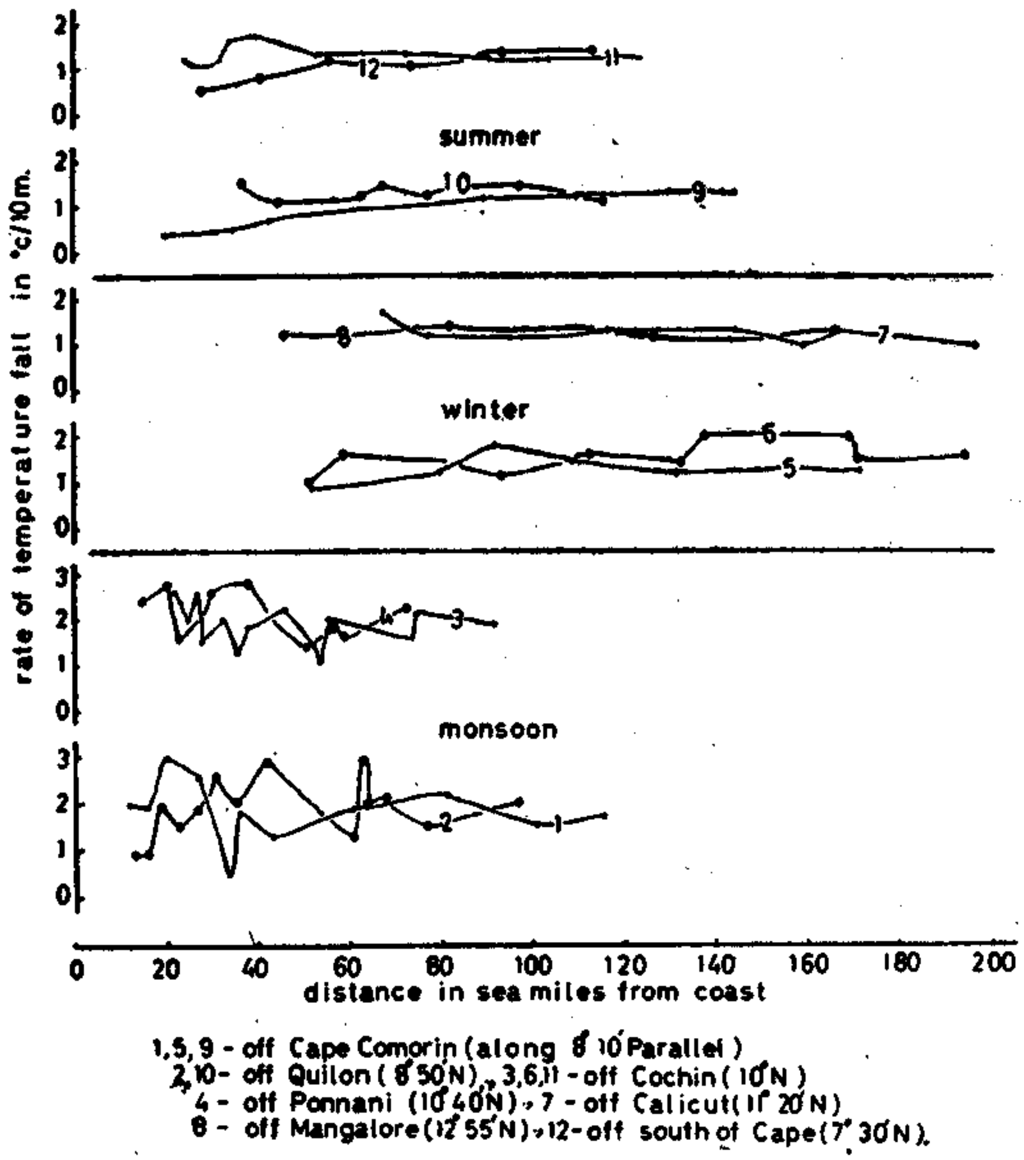

FIG. 6 The rate of temperature fall in the discontinuity layer.

currents are mutually adjusted in order to keep the geostrophic balance, if frictional forces can be neglected or assumed constant. The bottom friction at a given place may be assumed constant except it be a function of velocity of the current. But the wind-generated frictional forces will vary from season to season, so also the viscous forces in the sea. Therefore, these factors tend to disturb the geostrophic balance. The steady state of the flow will even be altered and accelerations may be brought into the stream by these frictional influences. However, within certain limitations, the relative currents may be deduced from the geostrophic balance. Accordingly, the thermocline must be elevated on the left of the current. The directions of currents so deduced are schematically represented by arrow-marks in Fig. 2.

During the monsoon period there is a single stream flowing southward. This stream is spread over the entire shelf of the region under investigation. As time passes on, from the monsoon to winter, a northerly current is established off the shelf. Adjacent to and on the seaward side of it there is the southerly current. But this southerly current is limited to the southern portion only. As the season changes from winter to summer, the northerly current which was set up, during winter completely disappears and the circulation breaks into different eddies. The southerly current which flows nearer to the coast in winter continues to persist in summer though it is limited to a narrower belt. Again, as the monsoon season replaces the hot weather season, in the cycle of the seasonal events, the southerly narrow stream of the summer spreads over the entire shelf and appears as a wide stream. Thus, the southerly stream of the current system prevails very near the coast all through the seasons of the year, though its strength and width change during different seasons.

The winter streams appear to be stronger than the monsoon current. All the streams appear to be stronger at the south-western region of the coast and they appear to be weakened and then spread with increase of latitude.

PART-B

SIMPLE CORRELATIONS

Attempts were made in the past (Buys, 1957; Carruthers *et al.* 1959; Marr, 1959; Pradhan and Reddy, 1962; Radovich, 1959; Subrahmanyan, 1959; Uda 1952; Walford, 1946) describing the fluctuations of mackerel and sardine of Indian waters and other regions and relating them with one or more of the hydrographical conditions. These descriptions or simple statistical correlations may not help much for forecasting the fisheries. Sometimes, such relations give opposite results. It is, therefore, necessary to seek for the cause and effect and do rigorous analysis in order to establish practical methods of forecasting the fisheries. This view point gains support from the opposing results of Walford (1946) and Marr (1959).

THE BEHAVIOUR OF THE INDIAN PELAGIC FISHERIES

It may be worthwhile to discuss the main features of the Indian sardine and mackerel fisheries. Fig. 7 which is prepared from the Quarterly and Annual reports published by the Central Marine Fisheries Research Institute, shows the oil

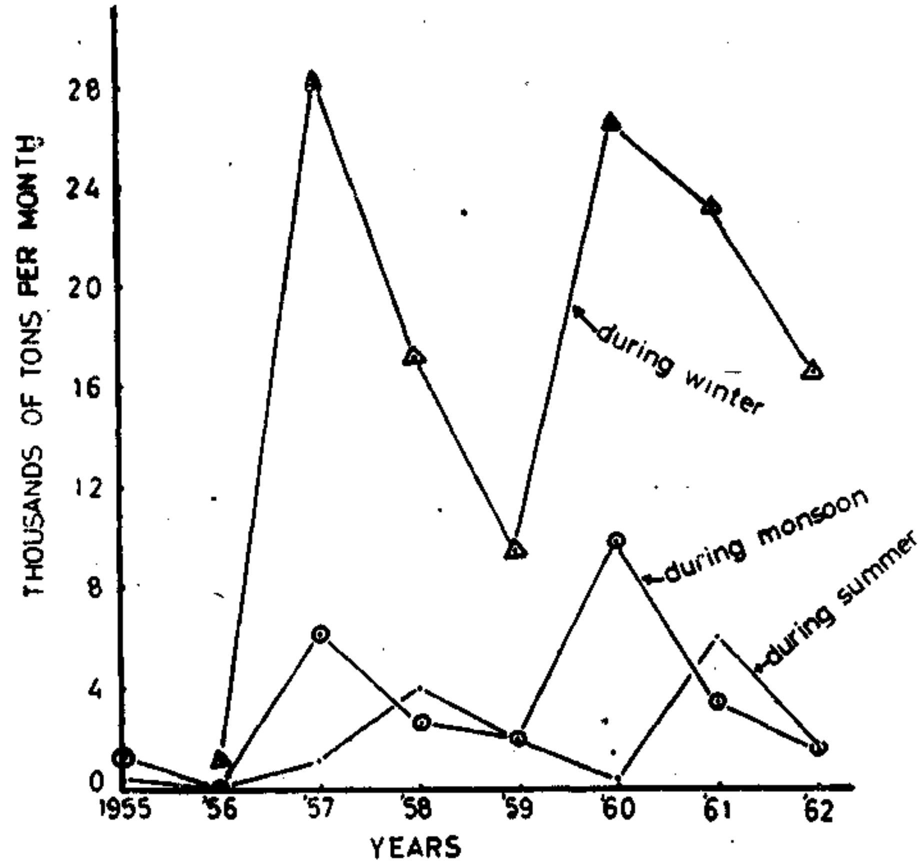

FIG. 7 The oil sardine catch

sardine landings during the three different seasons in different years. In preparing this figure the second quarter (April, May and June) is treated as summer (hot weather season), the third quarter (July, August and September) as monsoon and the fourth and the first quarters as winter season. Thus the catch per month during the different seasons is taken into consideration for comparing the seasonal trend of the catch, which is shown in Fig. 8. There is a tremendous progress of fish catch in the order of the seasons—summer, monsoon and winter.

There are some regional differences of sardine and mackerel fisheries of India which are no less important from the practical point of view of fishery forecasting.

According to the Kerala Fisheries Department, large shoals of oil sardine occur in the northern zone of Kerala Coast (Kerala Fisheries Department, 1962) and the fishery starts immediately after the southwest monsoon and lasts from September to March. The peak catch lasts from September to December. The

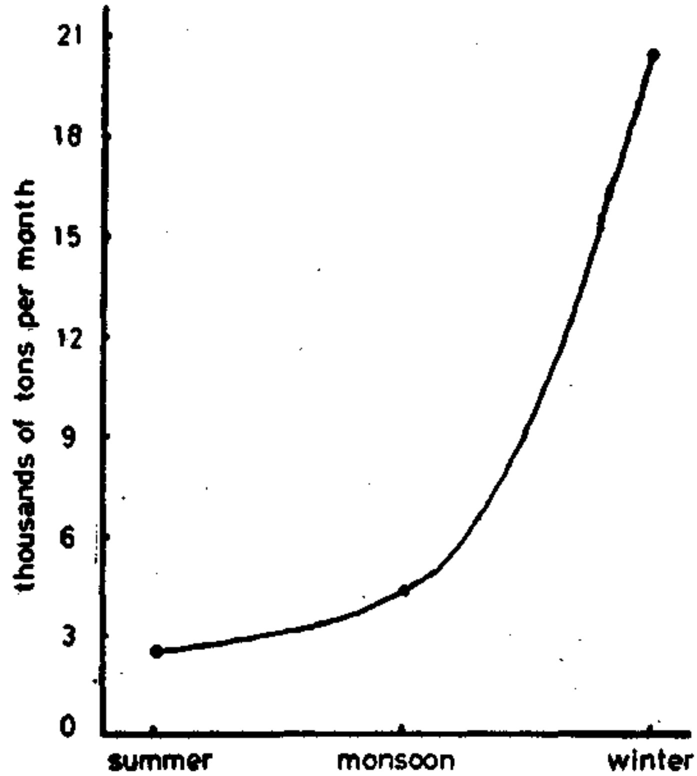

FIG. 8 The seasonal trend of the oil sardine catch.

mackerel fishery, like that of the oil sardine, is of great importance in the northern zone of Kerala coast. This fishery in the Kerala coast usually starts from the middle of August and ends in May, the peak months being October to December.

According to Nair (1959) the oil sardine fishery of India generally commences in July and terminates in March with the November-January portion representing the best period of the fishery.

Chidambaram (1950) pointed out that the sardines appear first in the Calicut region and then appear gradually in succession towards the north and begin disappearing in the north first and then near about Calicut and finally in the south. Mackerels also follow almost the same course of events (Panikkar, 1952).

Thus enough evidence is gathered that the pelagic fisheries of the oil sardine and mackerel, which strike the peninsula not right at its tip but a distance further north along the west coast, behave in a systematic way regionally and seasonally.

A CLUE TO THE PRACTICAL SOLUTION OF THE PROBLEM

From the above discussion it is clear that the pelagic fisheries, particularly the oil sardine and mackerel fisheries along the west coast of India, have definite regional and seasonal trends in their distribution. The clue to these seasonal and regional variations has to be found partly, if not wholly, in the variations of the pattern of the coastal currents. An interesting point here is that the catches are maximum during the period (winter season) when the northerly drift gets established along this coast. It is quite possible that the pelagic fisheries of the Indian West Coast are intimately related to these coastal drifts. Any effort to evolve a prediction system for the pelagic fisheries along this coast should take this factor into consideration. As a first step towards this achievement, it would be necessary to work out the structural details of this current system making direct current measurements (since there are many theoretical limitations to the indirect methods of computing currents). Further it is necessary to relate these data with the fish movements which can be obtained with reasonable degree of accuracy by tagging experiments. The basic data and information thus obtained will enable us to work out prediction system for the pelagic fisheries of the region.

Summary

Seasonal variations of thermocline depths in the region between Cape Comorin and Mangalore showed that the thermocline depths are low during the south-west monsoon season, moderate during the summer (hot weather season) and great during the winter season. Thermocline is necessarily pushed off the coast during winter. The depth of the thermocline increases seaward during summer and monsoon. The surface of the depth of the top of thermocline takes an inverted wedge shape about the shelf-edge with decreasing depth on either side of the 100 m. isoline of the depth of the top of the thermocline during winter. The depth again increases further off in the sea in the south-western part of the region during this season. The effect of the shallow bottom (near the coast) upon the thermocline position is illustrated.

The width of the range of salinity values associated with the thermocline top increases in the order of winter, monsoon and summer, the spread taking place towards the lower values. The ranges of temperature associated with the top of thermocline are, in general, slightly less during winter than those during monsoon and they are slightly more during summer.

The vertical rate of fall of temperature in the discontinuity layer is found to be independent of latitude or longitude, at least in the region of investigation. However, seasonal changes in the gradient of thermocline have been observed. The thermocline is sharpest during the monsoon, moderate during the winter and mild during the summer.

A system of seasonal currents is revealed by the distribution of the lines of equal depths of thermocline.

Based on a relationship between the coastal current pattern and the trends in the pelagic fisheries, the possibility of evolving a prediction system has been indicated.

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