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SALINITY AND THERMAL CHARACTERISTICS OF THE COASTAL WATERS OFF SOUTHWEST COAST OF INDIA AND THEIR RELATION TO MAJOR PELAGIC FISHERIES OF THE REGION*

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ABSTRACT

A study of the sea water temperature and salinity of the coastal waters along the southwest coast of India between Cape Comorin and Ratnagiri based on observations made along 6 sections for a period of 8 years is made use of for the study. The variations in the monthly mean sea surface temperature and salinity, the position of the thermocline and depth of salinity maxima were studied. Vertical time series sections were used to compare the variations noticed in the vertical oscillation of various isotherms in space and time. An attempt is made to identify the isotherm which exhibits maximum vertical oscillation. The net vertical movement of the water masses, was estimated based on the vertical oscillation of selected isotherm. Possible existence of convergence zones in the area under study was established with the help of horizontal salinity distribution maps. An attempt is also made to examine possible correlations of sea water temperature and salinity with the occurrence of oilsardine, mackerel and whitebait in the area under study.

INTRODUCTION

OF LATE it has been accepted that a reasonable solution to the problems of stock and recruitment, interaction between different species and inherent variability of natural systems will help us to manage the fisheries in a better way rather than basing the entire concept on Maximum Sustained Yield (Gulland, 1977). As in the case of terrestrial animals, the marine fauna including fishes also respond in varying degrees to changes in the oceanographic and climatological conditions. The valuable contributions made by Hela and Laevastu (1970) in this field assume great significance in this context.

The present study is aimed at observing the variations in space and time of sea water temperature and salinity within the coastal waters upto a depth of 150 m along the southwest coast of India between Ratnagiri (17°00′ N, 73°20′ E) and Cape Commorin (08°10′ N, 77°30′ E) (Fig. 1). The study also attempted possible correlations between the observed parameters and the occurrence and migration of the major pelagic fishery resources such as sardine, mackerel and anchovy in the area under study.

A number of investigations were reported from the area selected for the study and adjacent waters with major contributions from Devanesan (1943), Chidambaram and Menon (1945), Bhimachar and George (1950), Banse (1959), Ramamirtham and Jayaraman (1961), Edelman (1960), Pradhan and Reddy (1962), Patil and Ramamirtham (1963), Patil *et al.* (1963, 1964), Murty (1965), Murty and Edelman

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(1966), Sharma (1966, 1968), Darbyshire (1967), Banse (1968), Anand *et al.* (1968), Prabhu *et al.* (1972), Noble (1972), Rao *et al.* (1973) and Antony Raja (1974).

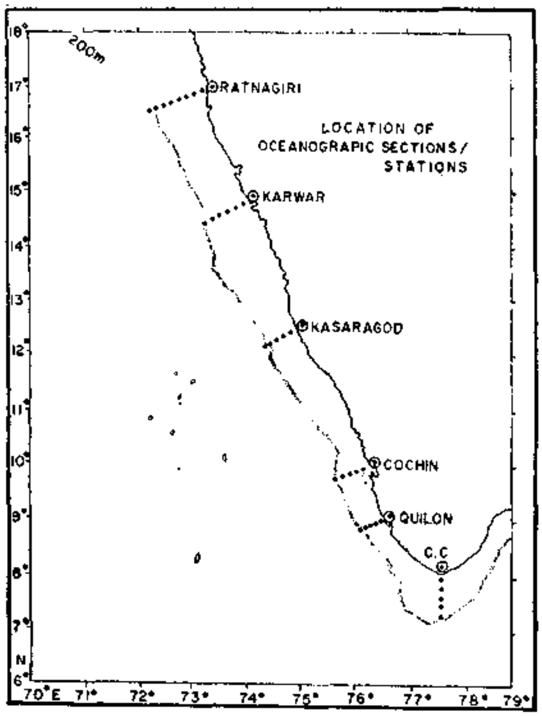

Fig. 1. Location of oceanographic sections/stations.

Some detailed studies were made in the coastal waters of the southeastern Arabian Sea using Research Vessels '*Kalava*', '*Conch*', '*Varuna*' and '*Gaveshani*'. The relevant departmental reports (classified) brought out by the Naval physical and Oceanographic Laboratory (erstwhile Indian Naval Physical Laboratory), Cochin (Sundararaman *et al.*, 1963, 1964), the various reports published by UNDP/FAO Pelagic Fishery Project, Cochin (Anon., 1973, 1974, 1976), relevant reports pertaining to the International Indian Ocean Expedition, the reports/bulletins by the Central Marine Fisheries Research Institute, Cochin, the Fishery Survey of India, Bombay, Integrated Fisheries Project, Cochin and the National Institute of Oceanography, Goa are worth mentioning in this context.

The author wishes to express his sincere gratitude to Dr. P. S. B. R. James, Director, CMFRI, Cochin for his encouragement and to Dr. A. V. S. Murty, CMFRI, Cochin for going through the manuscript and offering valuable guidelines and corrections.

Data and Methods

The basic hydrographic and fishing data collected during 1971-1978 on board the fishery research vessels 'R. V. *Rastrelliger*' and 'R. V. *Sardinella*' of UNDP/FAO Pelagic Fishery Project, Cochin and 'R. V. *Varuna* of Integrated Fisheries Project, Cochin were utilised.

Most of the sections cover only the continental shelf within a distance of approximately 80 km which constitute the environment for a significant part of the Indian fisheries. Considerable seasonal variations are also characteristic of this environment.

Salinity values upto 150 m depth alone were considered in the present study. The stations within the continental shelf were fixed at an interval of 16 km. Before the arrival of the large vessel '*Rastrelliger*', '*Sardinella*' and '*Varuna*' worked the sections parallel to the latitudes (1971 to 1972) and from 1973 '*Rastrelliger*' sections were worked at right angles to the coast line. Special care was taken to ensure that the different sections were covered within the shortest possible time to get synoptic picture of the hydrographic conditions during each survey. During 1971-'72 salinity estimations were made by the standard titration method. However from 1973 onwards a salinometer was used. A quality analysis of temperature and salinity data resulted in too large a scatter in the salinity determination done by titration method in 1971 and 1972. Therefore salinity values estimated during 1971 and 1972 are excluded in this report.

Nansen reversing thermometers were used in pairs to minimise possible errors. Bathythermograph observations, using a shallow, medium and deep bathythermographs were also made at all the stations except the shallowest stations located near the coast. The top depth and width of the main thermocline were determined from the bathythermograms. In order to minimise the fluctuations in the various environmental parameters, which are likely to arise out of coastal processes and also diurnal influence, it was decided to consider parameters at the second station from the coast at a depth of 10 m as representative of the conditions characteristic of the surface layers.

Acoustic surveys and fishing experiments for identification and sampling were undertaken on board '*Sardinella*' and '*Rastrelliger*', when the smaller vessel '*sardinella*' surveyed the shallow parts of the shelf upto 40 m depth at 12 km cruise track intervals, the larger vessel '*Rastrelliger*' covered the deeper parts of the shelf and continental slope with the cruise track interval at 24 km. Both the vessels were fitted with SIMRAD scientific sounders EK 38 (deep) EK 120 and with QM Echo Integrators. On the basis of the patterns of recording and the results of relevant fishing experiments the integrator readings were allocated to different groups of fishes.

'*Rastrelliger*' used 4 types of bottom trawls *viz.* High opening bottom trawl. Hard bottom trawl, Large high opening bottom trawl and a Lobster bottom trawl. The vessel also used a standard pelagic trawl as well as mid water trawl. '*Sardinella*' used two types of high opening bottom trawls and one type of pelagic trawl. This vessel also operated the purse-seine and the gill-seine. Fishing was always carried out based on recordings of the echo sounder and the sonar. Depth of operation in the case of pelagic trawl was decided by operating the trawl sonde. Usual trawling speed was about 3 knots.

Results and Discussion

Hydrography

Hydrographic data collected from the oceanographic sections off Ratnagiri, Karwar, Kasaragod, Cochin, Quilon and Cape Comorin (Fig. 1) provided fairly good information on the seasonal fluctuations noticed on the shelf.

Ratnagiri section

The mean monthly sea surface temperature (at a depth of 10 m at the second station from the coast) ranged between 26.50°C and 30.03°C. The maximum was observed in May and minimum in February. The surface mixed layer, on an average, extended to a depth of 39 m during December-February. The mixed layer became non-existent or comparatively very shallow with a minimum thickness (11 m) during October and November. Positive inversions were characteristic of the surface layers (40-150 m) during the period December-March.

The mean monthly surface salinity varied between 34.78‰ and 36.02‰ with the maximum in May and the minimum in October. Salinity was found to be closely related to the influence of the low saline equatorial waters in the northerly current and the advection of the high saline northern Arabian Sea waters in the southerly current. The salinity maximum observed at the surface during May has possibly resulted out of the influence of high saline north Arabian Sea water reaching the area in the southerly flow. Similarly the surface salinity minimum in October is possibly related to the influence of low saline equatorial waters being carried towards Ratnagiri area in the northerly flow. The salinity maximum characteristic of tropical oceans was observed between the depths 30-50 m and 100-150 m during the southwest monsoon and post-monsoon season respectively.

Karwar section

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

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

Kasaragod section

The mean monthly surface temperature ranged between 21.78°C and 29.70°C. The minimum was in September and the maximum during April. The minimum value was associated with the upwelling of subsurface waters to surface levels during the Southwest Monsoon and maximum during the summer season. The mixed layer, on an average, extended to a depth of 56 m during December-February and became very shallow with minimum thickness (13 m) during June - September. Positive inversions were characteristic of the surface layers during the period December-March.

The mean monthly surface salinity varied between 32.71‰ and 35.55‰. The minimum value was during January and the maximum during May. The salinity maximum characteristic of tropical oceans, was found at depths between 30 m (southwest Monsoon) and 150 m (Post-monsoon).

Cochin section

The mean monthly sea surface temperature varied between 23.57°C and 30.01°C. The minimum was during September associated with the process of upwelling and maximum in April.

The mixed layer, on an average extended to a depth of 61 m during December-February. The mixed layer became very shallow with minimum thickness (10 m) during June-September. Positive inversions were present at the surface levels during December-March between the depths 50-150 m.

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

Quilon section

The mean monthly sea surface temperature varied between 24.26°C and 29.82°C. The minimum was in September associated with the presence of cold upwelled waters at the surface level and the maximum in April. The surface mixed layer, on an average, extended to a depth of 66 m during December-February. The same became very shallow with minimum thickness (16 m) during June-September. Positive inversions were present at the surface levels during December-March period.

The mean monthly surface salinity varied between 33.34‰ and 35.34‰. The minimum value was in February and the maximum in October associated with the presence of high salinity Arabian Sea waters at the surface. The salinity maximum was between depths 30 m (Southwest monsoon) and 150 m (Post-monsoon).

Cape Comorin section

The mean monthly sea surface temperature varied between 21.13°C and 28.73°C. The minimum was during August and the maximum in April. The mixed layer, on an average, extended to a depth of 63 m during December-February. The same became very shallow with minimum thickness (20 m) during June-Sept. Positive inversions were present at the surface levels during December-March period.

The mean monthly surface salinity varied between 33.03‰ and 35.25‰. The minimum value was during December and the maximum during October.

Seasonal and spatial variations of major hydrographic features in the area under observation

Watermasses: According to Darbyshire (1967) there are three major watermasses present on the shelf *viz.* (1) the Indian Ocean equatorial water (temperature 17°C with a minimum of 34.9‰ salinity) present at the deeper levels on the continental slope, (2) the Arabian Sea water (temperature between 17°C and 27°C associated with maximum salinity of 35.5‰ to 36.3‰) and (3) the equatorial surface water (temperature between 27°C and 30°C and a wide salinity range of 30‰ to 34‰). Banse (1968) indicated that during the peak of southwest monsoon a watermass is formed by the mixing of low salinity surface water and the denser upwelled water. The resulting sub-surface water has a lower salinity when compared to the Arabian Sea water and a wide temperature range down to a minimum of around 20°C.

Convergence zone : The existence of convergence zone in the study area is evident from the horizontal salinity gradients observed during the period January-March (Figs. 2, 3, 4). In 1974, the surface salinity increased from 33‰ to 35‰ between Karwar and Ratnagiri. This difference was less pronounced in 1975. In 1973 a similar zone was observed between Kasaragod and Calicut sections. The variations observed in the surface salinity suggest that the convergence zone exhibit seasonal variations spreading northwards with the intensity of the northerly

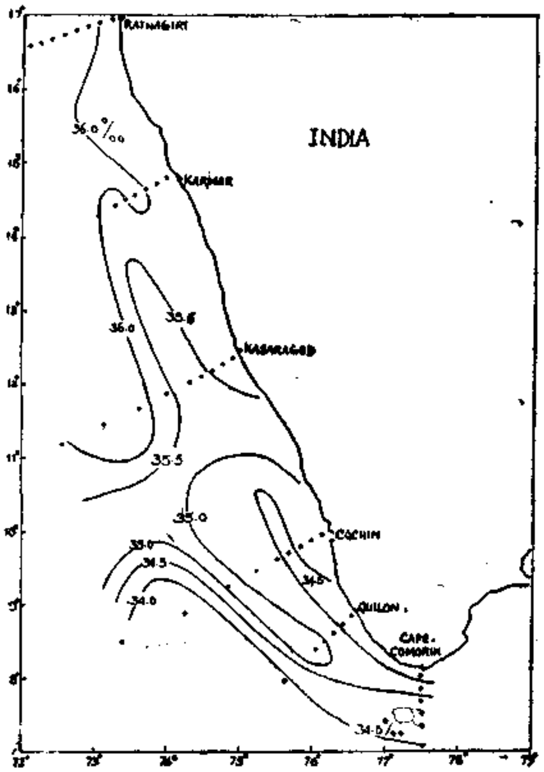

Fig. 2. Horizontal distribution of sea surface salinity (Jan.-Mar. 1973) (Source: PFP Progress Report, 16).

flow which carried equatorial waters towards northern latitudes (Darbyshire, 1967). During the southwest monsoon season the salinity distribution at the surface levels is not indicative of the convergence zone mainly due to the effect of rainfall and river runoff.

Sea water temperature : The monthly mean surface temperature for the period 1973-1978 shows large variation in space and time. In general comparatively low values were observed during January - February and July-October, the lowest being in August

(21.13°C) off Karwar. The high values ware associated with the summer season, just prior to the onset of the southwest monsoon. A steady increase in the highest monthly mean temperature (1973-'78) from south to north was

and two minima (July-August and December-January). Off Ratnagiri the maxima occurred in March, June and October and minima in September and December-January.

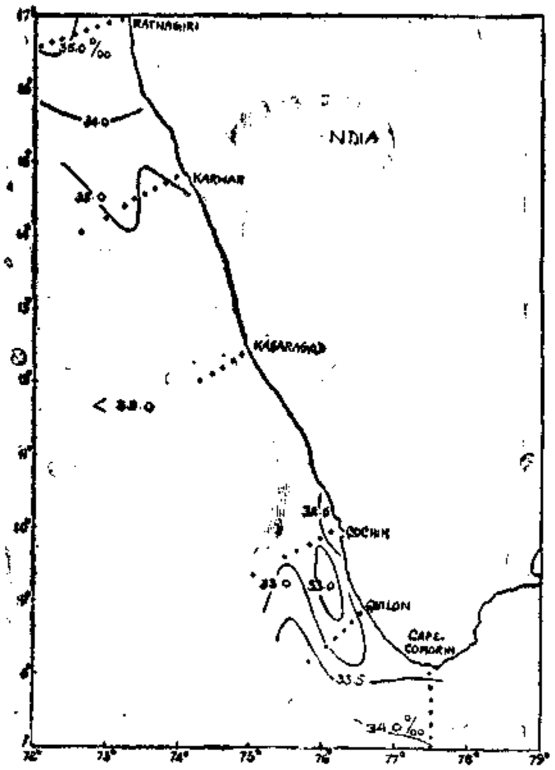

Fig. 3. Horizontal distribution of sea surface salinity (Jan.-Mar. 1974) (Source: PFP Progress Report, 16).

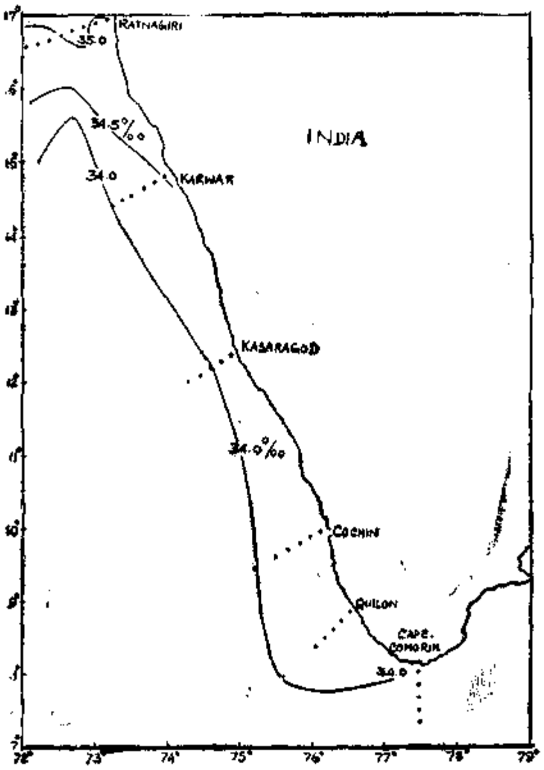

Fig. 4. Horizontal distribution of sea surface salinity (Jan.-Mar. 1975) (Source: PFP Progress Report, 16).

noticed between Cape Comorin and Karwar (28.73-30.15°C). The low values were noticed during January-February and also during the peak upwelling season (July-October). The lowest values were observed in those areas where the intensity of upwelling was comparatively high (between Cape Comorin and Kasaragod). A comparison of mean surface temperature for the period 1972-1978 for Cochin and Cape Comorin sections revealed two maxima (April-May and October-November)

The mean depth of the top of the thermocline shows large variations from season to season (Table 1). The top of the thermocline was deepest during the period December to February and the same reached the surface layers during June-September (south of Cochin) and October-November (north of Cochin).

The vertical time series sections of water temperature for sections representing the southern region (Cape Comorin and Quilon) (Figs. 5, 6) Central region (Cochin and Kasaragod—Figs. 9 and 10) were made use of

TABLE 1. *Mean depths of top of thermocline at different oceanographic sections* (1973-1978)

Section	Shallowest (m)	Period	Deepest (m)	Period
Ratnagiri	11	Oct.-Nov.	39	Dec. to Feb.
Karwar	10	Oct.-Nov.	61	Do.
Kasaragod	13	June to Sep.	56	Do.
Cochin	10	Do.	61	Do.
Quilon	16	Do.	66	Do.
Cape Comorin	20	Do.	63	Do.

to compare the variations noticed in the vertical movement of the various isotherms in space and time. The net vertical movement of isotherms was estimated along different sections and it was found that the 23°C isotherm exhibited maximum movement on the vertical plane (Table 2). A comparison of the upward movement of the isotherm for the period 1973-'78 indicated the maximum (110 m) off Quilon and minimum (79 m) off Cape Comorin. During 1977 (July), the isotherm reached the very surface both off Quilon and Cape Comorin.

Thermal inversions : A positive thermal inversion can result in the presence of a surface current where some of the water in the thermocline may also move in the direction of flow overriding the deep water Pillai *et al.* (1977) observed positive inversions in the northern Arabian Sea during March-April and their absence in May was attributed to the comparatively weak circulation system prevailing in this region during the transition period between the northerly and southerly currents.

A careful examination of the bathythermograms pertaining to different stations/ sections for the period 1971-'78 indicated that positive inversions generally associated with

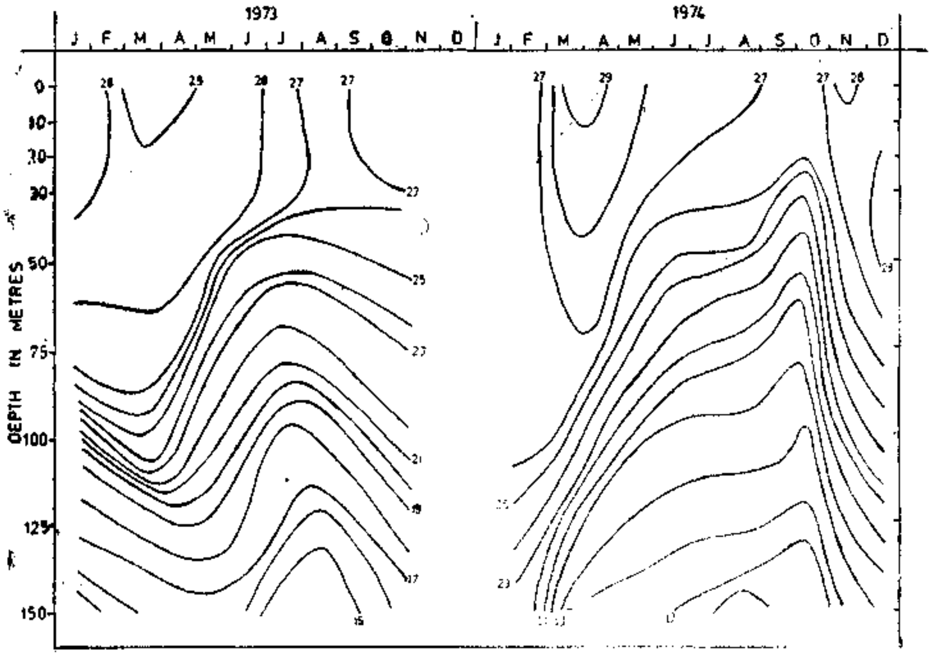

Fig. 5 a. Vertical time section for sea water temperature off Cape Comorin (1973, 1974).

the bottom of the thermocline, were characteristic of all the stations except during May, June and September (Cape Comorin); April and September (Quilon); August and September (Cochin); May, June and July (Kasaragod) and June, July and September (Ratnagiri). The positive inversions were mostly found at the surface levels during the southwest monsoon/upwelling season and the depth of occurrence was maximum during the winter season. Their absence was noticed during the transition between the northerly and southerly currents.

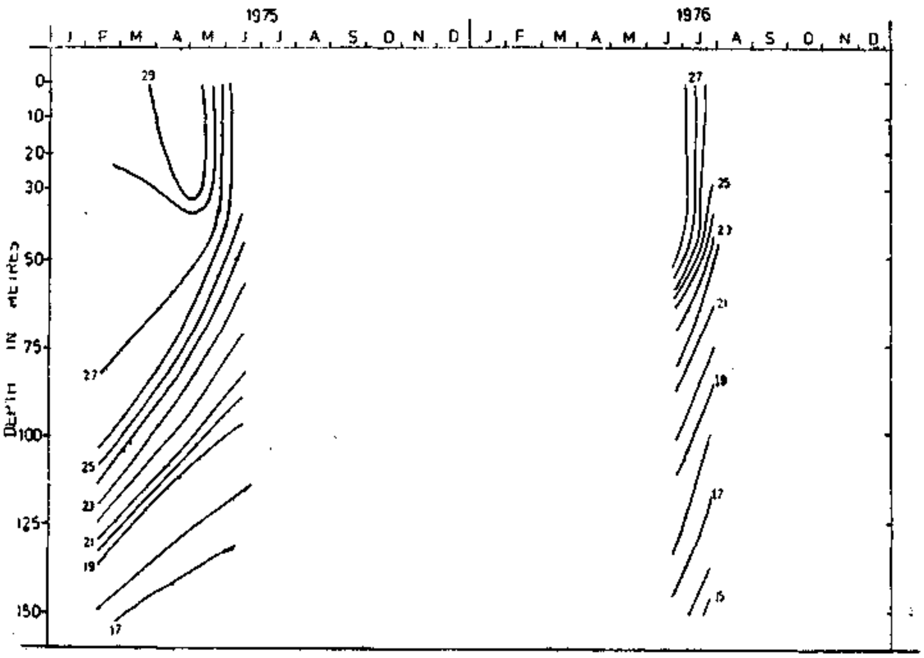

Fig. 5 b. Vertical time section for sea water temperature off Cape Comorin (1975, 1976).

TABLE 2. *Position of 23°C isotherm (sectionwise/yearwise) within the area under observation*

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

Salinity: The monthly mean surface salinity for 1973-'78 for the different sections also indicated two peaks, one during May-June just before the onset of the southwest monsoon and another during September-October immediately after the southwest monsoon. The lowest values were associated with the monsoon rain and the river run off which showed lot of variations from one section to the other in different years. The monthly mean surface salinity at 10 m from the coast varied between 32.50‰ and 36.12‰. The salinity maximum characteristic of tropical oceans was found at the depths 100 to 150 m during the northeast monsoon and between 30 to 50 m during the southwest monsoon. The variations in salinity which are mainly brought about by the rainfall, river run-off and the prevailing seasonal surface currents are characteristic of the surface layers above the salinity maximum layer.

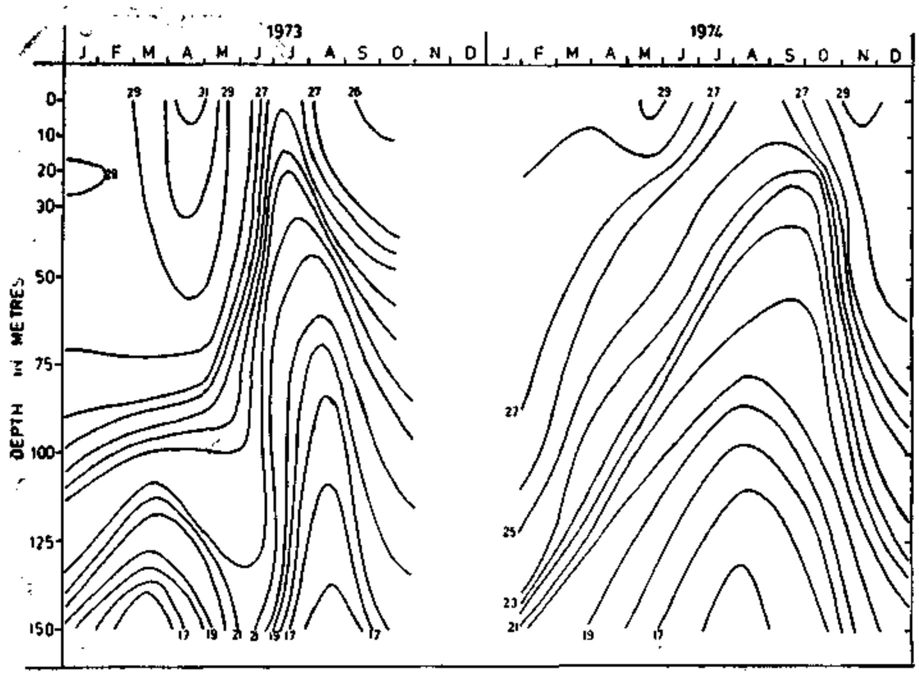

Fig. 6 a. Vertical time section for sea water temperature off Quilon (1973, 1974).

The surface salinity was highest at Karwar and Ratnagiri sections during May/June (35.6‰ to 36.12‰). Comparatively low saline water (33.03‰) was observed at the surface off Cape Comorin in December when the equatorial surface water was advanced northwards. Sewell (1929) attributed the lowering of salinity during December and January in the Palk Bay and the Gulf of Mannar to the southerly current along the east coast. During this month the salinity value at the surface showed a steady increase from 33.03‰ off Cape Comorin to 35.08‰ off Karwar and Ratnagiri.

A comparison of monthly mean surface salinity values for the period 1973-'78 indicated the presence of two maxima (April and December) and one minima (July) for Ratnagiri, two maxima (April and October and two minima (July and December) for

Cochin and two maxima (May and October) and two minima (February and December) for Cape Comorin. The maxima occurred comparatively late in the southern sections (during April off Ratnagiri and during October off Cape Comorin) and these were mainly associated with the advection of the high salinity Arabian Sea water in the southerly flow and the presence of high salinity bottom water brought upward to the surface levels in areas where upwelling activity was observed. The minima were associated with the monsoon rain and the resultant river run-off and also the incursion of the low saline equatorial surface waters in the northerly flow. The minima occurred first in the southern region and progressively moved northwards following the trend in monsoon rainfall and the development of the northerly flow.

In general the sections north of Kasaragod exhibited comparatively higher salinity conditions than the southern sections. At greater depths beyond 100 m there is a decreasing trend in salinity from north to south. It is quite likely that the comparatively high saline north Arabian Sea water is spreading southwards slowly losing their high salinity characteristics. This is in agreement with the general circulation in the upper layers in tropical and subtropical waters. (Sverdrup *et al.*, 1942 ; Wyrtki, 1973 ; Darbyshire, 1967). The salinity maximum associated with the main thermocline probably represents an intrusion of high saline waters below the less saline surface layers towards the Equator.

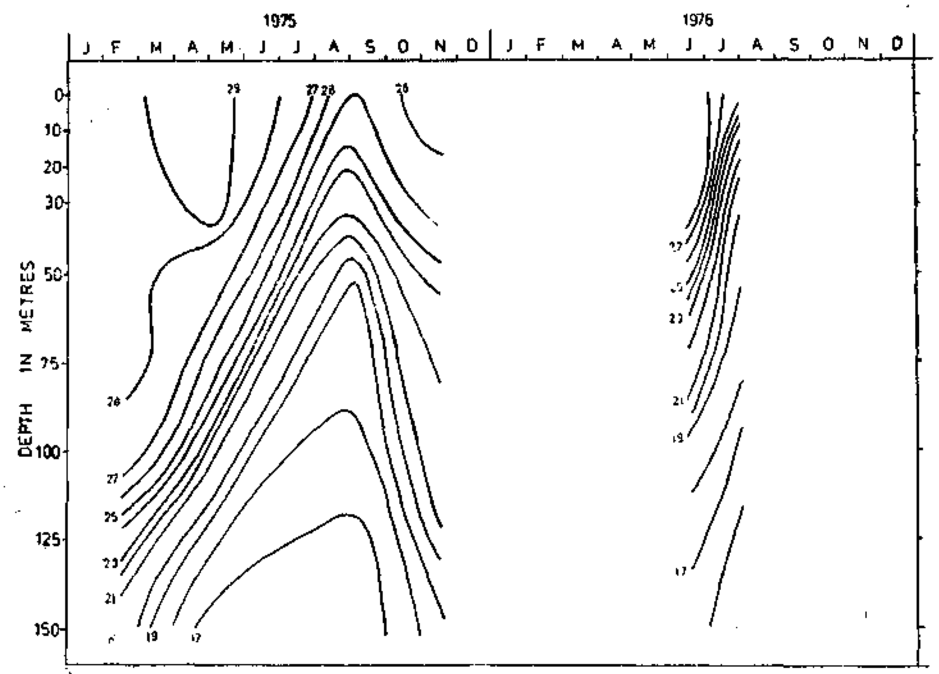

Fig. 6 b. Vertical time section for sea water temperature off Quilon (1975, 1976).

Possible correlations between oilsardine, mackerel and whitebait fishery and observed oceanographic/biological parameters

Oilsardine and mackerel : The oilsardine *Sardinella longiceps* contributes a major commercial fishery yielding about 15 to 20%

of the total marine fish landings in India. Its fishery is characterised by wide fluctuations both seasonal and annual. The highest abundance and large scale shoaling have been observed off Kerala and Karnataka Coasts (CMFRI, R & D series, 1986). The findings of the erstwhile FAO/UNDP Pelagic Fisheries Project confirmed that "sardines spawn in shallow water mainly in the near shore areas between latitudes 11°30′ N and 15°30′ N. During the peak of southwest monsoon patchy concentrations of oilsardine larvae were observed in the central part of the southwest coast. Oilsardine is a typical schooling species which occurred in a band along the southwest coast mainly within 40 km off shore. It's schooling pattern was found to be associated with upwelling on the shelf. After the monsoon when the upwelling ceases, the school starts to disperse. The oilsardine then moved closer to the coast and become available to the shore based fishery. However part of the stock remains more offshore on the shelf throughout the year consisting mainly of adult fish".

High concentrations of Indian mackerel *Rastrelliger kanagurta* occurred along the southwest coast. Contribution of mackerel to the marine fish catches of the country during 1965-'84 increased from 2 to 20 per cent with an average of 6 per cent. Mackerel is migratory in habit and its fishery is seasonal. High catches occur during September-November along the southwest coast. It is known to breed on the shelf outside the conventional area during Pre-and Post-monsoon months (CMFRI, R & D series, 1986). The observations made by PFP indicated that mackerel spawn during most of the year, particularly from April to October, the peak spawning being observed during April-May. Larvae and juveniles were most frequently observed between 09°00′ and 13°00′N at depths of about 13 m. Mackerel occur in schools at or near the surface depending on

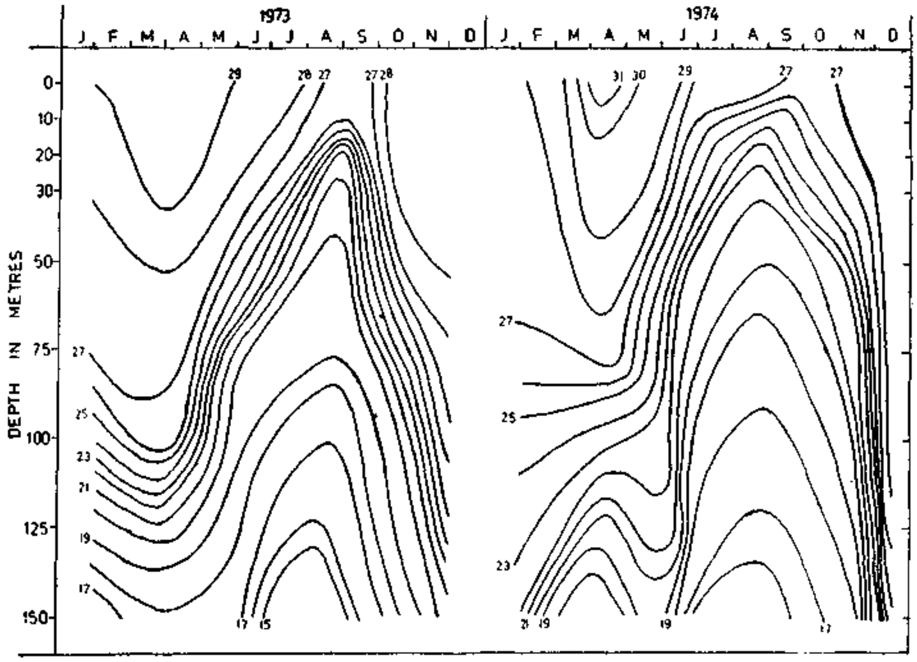

Fig. 7 a. Vertical time section for sea water temperature off Cochin (1973, 1974).

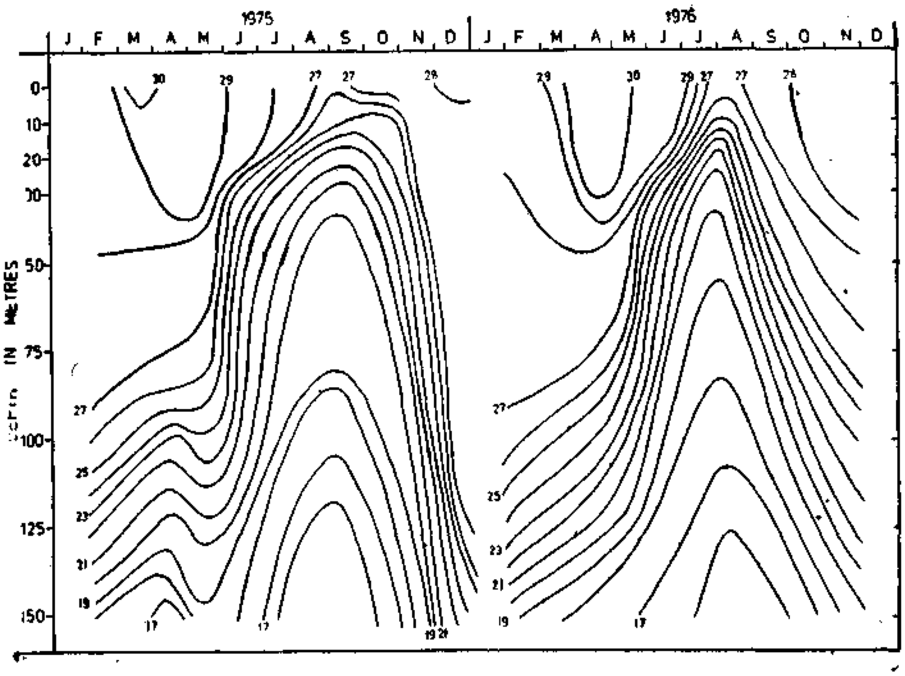

Fig. 7 b. Vertical time section for sea water temperature off Cochin (1975, 1976).

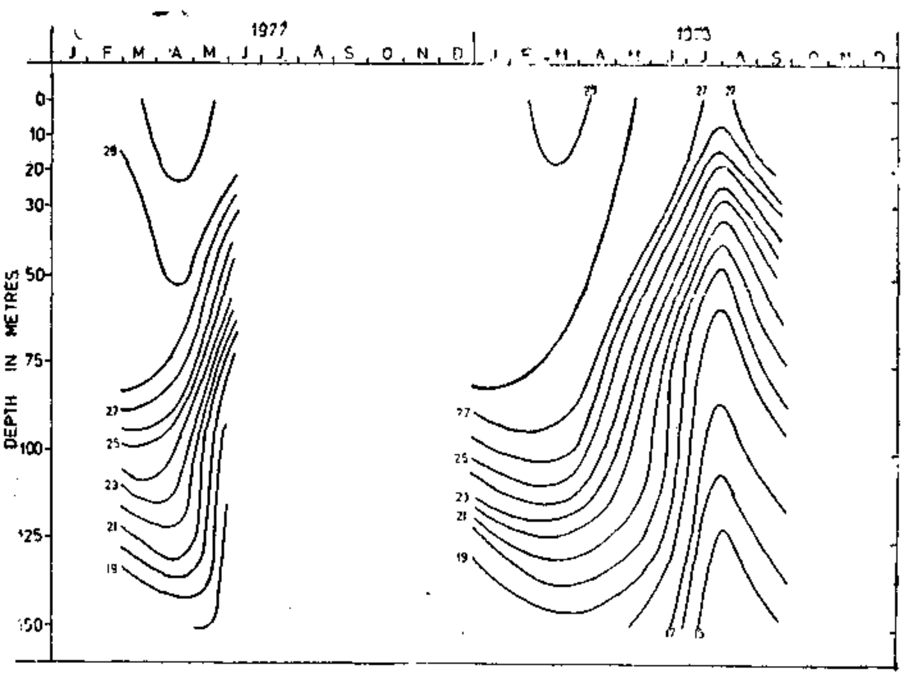

Fig. 7 c. Vertical time section for sea water temperature off Cochin (1977, 1978).

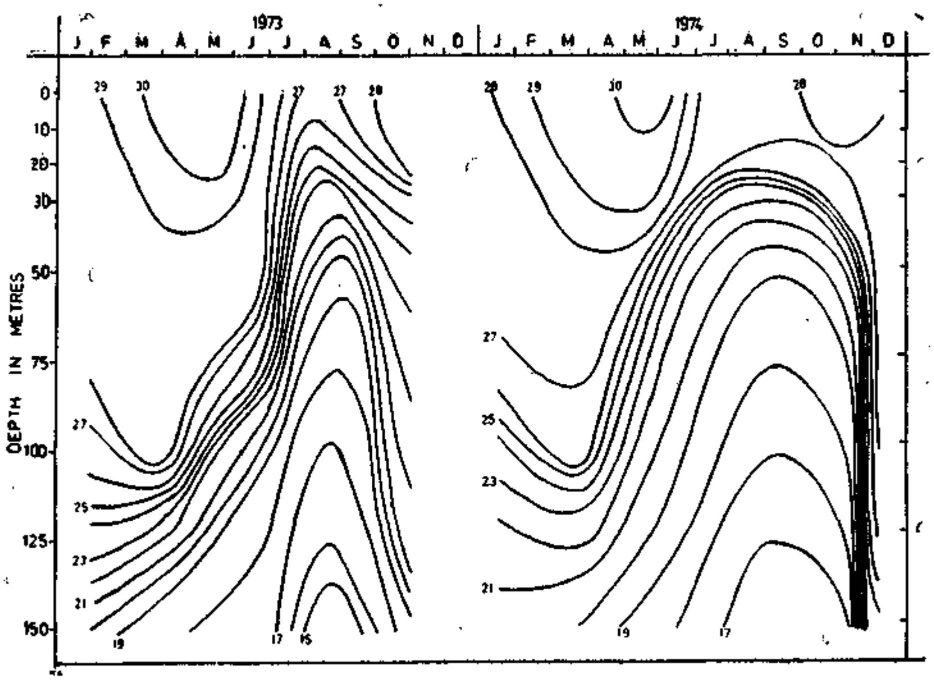

Fig. 8 a. Vertical time section for sea water temperature off Kasaragod (1973, 1974).

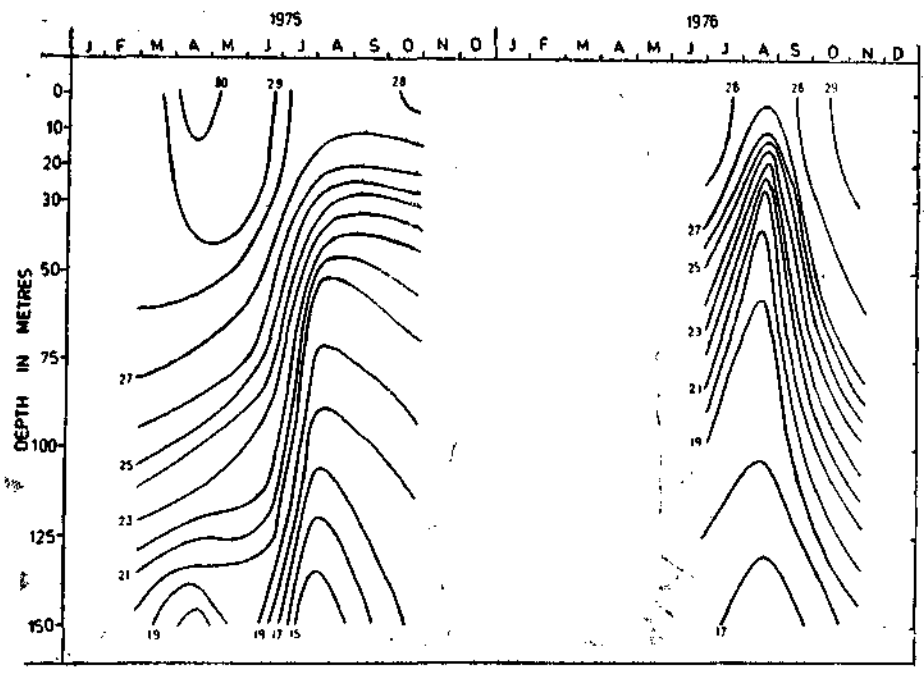

Fig. 8 b. Vertical time section for sea water temperature off Kasaragod (1975, 1976).

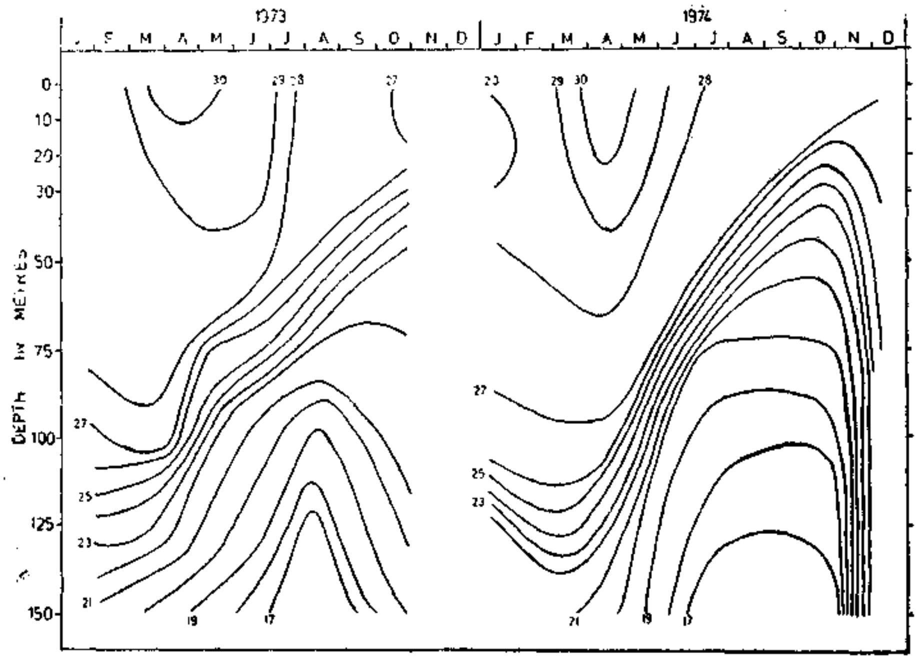

Fig. 9 a. Vertical time section for sea water temperature off Karwar (1973, 1974).

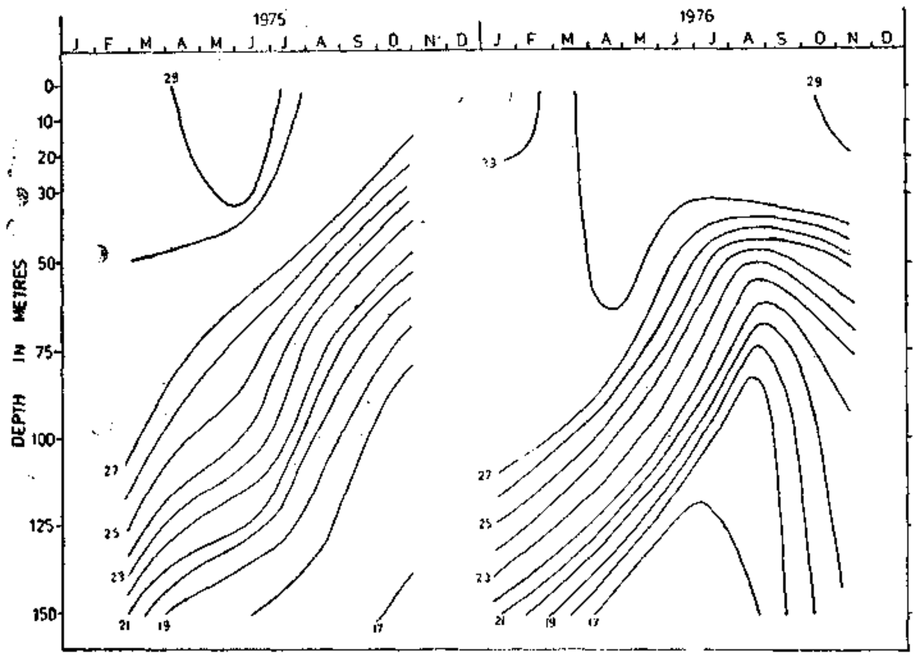

Fig. 9 b. Vertical time section for sea water temperature off Karwar (1975, 1976).

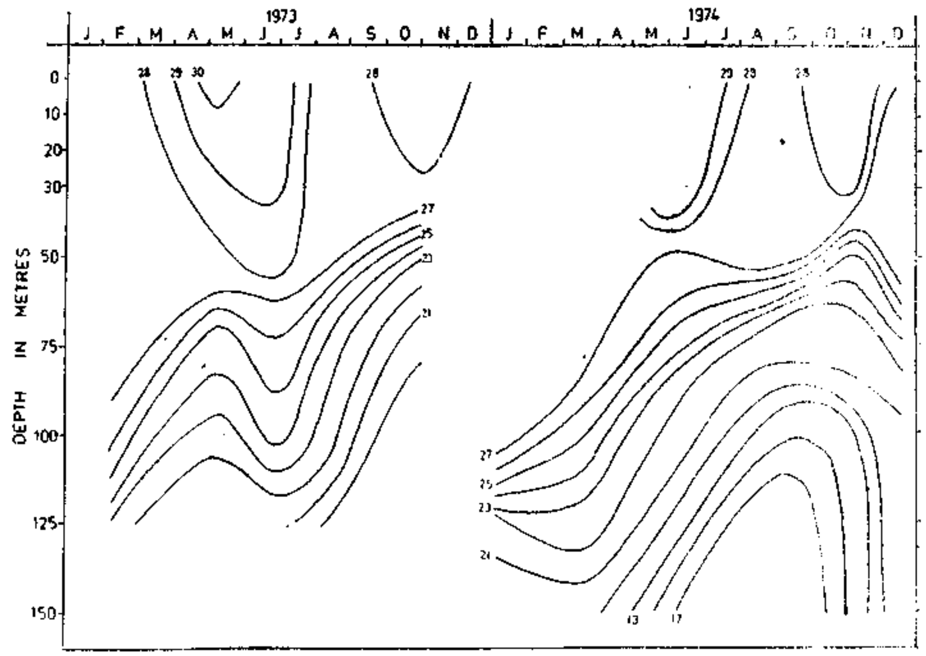

Fig. 10 a. Vertical time section for sea water temperature off Ratnagiri (1973, 1974).

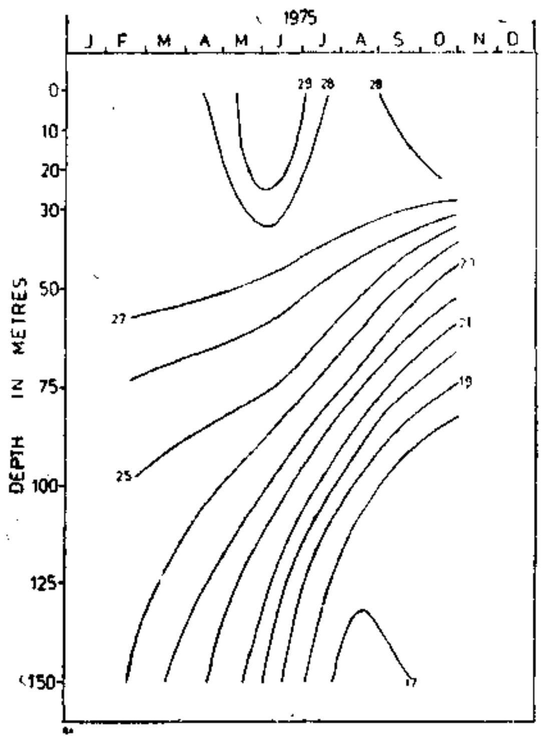

Fig. 10 b. Vertical time section for sea water temperature off Ratnagiri (1975).

local environmental conditions. The congregation of fish in the surface layer is more pronounced in the upwelling season. After the monsoon when the upwelling ceases and plankton become less abundant, the mackerel stock disperses. The juveniles move closer to the shore, but evidently much of the adult stock remains in offshore waters. Mackerel was generally most abundant in the area between Cochin and Mangalore, but in 1972 and 1975 they were evenly distributed along the southwest coast (Anon., 1976).

Panikkar (1949) observed that delays in the onset of monsoon on the Indian Coast are often followed by delays in the fishing seasons for mackerel as well as oilsardine. Bhimachar and George (1952) observed that the mackerel landings show their peak and coincide with or follow the abundance of plankton.

Noble (1972) reported an inverse correlation existing between surface temperature and duration of mackerel fishery off Karwar. During 1955-1956 and 1956-1957 the minimum surface temperature during the southwest monsoon period decreased with a corresponding increase in the duration of the mackerel fishery. During 1958-1959 the minimum temperature once again dropped to the lowest value for the previous 11 year period and the mackerel fishery season was the longest. During 1961-1962 the surface temperature recorded an increase during the southwest monsoon period and the duration of the fishery was the shortest. According to Murthy (1965) the clue for a seasonal and regional variations of both sardine and mackerel fishery has to be found partly, if not wholly, in the variations of the pattern of the coastal currents. According to him catches are maximum during winter season when the northerly drift gets established along the coast.

According to Rao *et al.* (1973) the oil sardine fishery dominates between Alleppey and Malpe and mackerel fishery between Calicut and Malwan. The northern areas appear to be more favourable for mackerel fishery probably due to a sudden increase in salinity occurring northwards from the region off Mangalore. December appears to be the peak season for oil sardine and October for mackerel. In December sinking of the offshore waters (coastal convergence) occurs over the shelf and a well defined thermal layer of about 75-100 m thickness is present along the west-coast (Ramamirtham and Jayaraman, 1961). It is well known that convergence brings in concentration of zooplankton (Hela and Laevastu, 1970). It was observed that zooplankton dominates in the food of oilsardines (Noble, 1972). Hence the abundance of oilsardines may be related to the phenomenon of the convergence along the coast. Rao and Rao (1957) have observed that Juvenile mackerel is selective in its food habit and adult ones are planktonic feeders. Hence it is probable that areas, where plankton productivity is high, constitute a favourable environment for mackerel.

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

Pradhan and Reddy (1962) found an inverse correlation between annual rainfall and mackerel catches off Calicut. The sardine fishery at Ullal was lowest (52.1 t) in 1963-1964 when the rainfall was heaviest (306.5 cm). The catches were better during 1965-1966 and 1966-1967 (283.7 t and 385.6 t respectively) *i.e.* when the annual rainfall was comparatively low (274.1 cm and 283.6 cm respectively) (prabhu *et al.*, 1972).

During the peak of southwest monsoon rainfall, the surface salinity falls substantially along the coast due to rain and river run-off. The influence of the southward spreading of high salinity Arabian Sea water during this season is nullified by the rainfall and river run-off. But the situation is reverse with the northward spreading of upwelling. Experimental fishing conducted by '*Rastrelliger*' and '*Sardinella*' revealed that both mackerel and oilsardine move along with the northward spreading of the upwelling condition. The northward migration of these fishes is confined to the northern limit of the region of upwelling *viz.*, Karwar. It is possible that the comparatively higher salinity and low temperature of upwelled waters favoured both oilsardine and mackerel.

During March-April it was found that the surface temperature increased and the shelf was occupied by comparatively high temperature and high saline waters. Possibly to avoid this high temperature, both oilsardine and mackerel were found migrating away from the coast into deeper water during March-April. The results of fishing operations conducted by the project vessels clearly indicated this position. A comparison of the monthly mean temperature (10 m depth and 2nd station from the coast) for the period July-October for the upwelling area between Quilon and Karwar indicated a mean temperature range of 23.4 to 26.4°C. In the Ratnagiri section the same varied between 27.5°C and 28.3°C during the same period. From these contrasts in the spatial variation of sea water temperature and the northern limit of the fishery for oilsardine and mackerel, it could be inferred that these fishes have less tolerance for temperature above 27.0°C. After March when the sea surface temperature increased much about the limit of tolerance (27.0°C), the fishery gradually subsided and by April-May these fishes moved away from the coast to deeper waters of comparatively favourable conditions.

During 1976 (June-July) some of the densest concentrations of breeding oilsardine were located off Mt. Delli where the temperature gradients were comparatively less (26° to 27°C), perhaps it would mean that oilsardines prefer areas with comparatively less vertical temperature gradients for breeding purposes and normally they moved away from the coast in search of suitable environment once they attain the required stage of gonadal maturity.

When the process of upwelling intensifies comparatively lower temperature and higher salinity subsurface waters slowly rises along the continental shelf towards shallower areas. Because of the comparatively low oxygen content of deep waters it was observed that part of the fish population moved in front of it into shallow surf mixed waters and part moved offshore away from the centre of strong upwelling. It was found that the upwelled water gets oxygenated within a short time due to contact with atmosphere and also due to wind action. These nutrient-rich bottom waters provide a very good habitat for the growth of phytoplankton followed by zooplankton. The plankton bloom attracts the plankton feeding fishes which slowly move behind the northward spreading of the upwelling to take advantage of the plankton bloom. There is always a time lag between the arrival of subsurface water at surface levels through the process of upwelling, the subsequent plankton bloom and the movement of oilsardine and mackerel schools to take advantage of the plankton bloom. The immediate effect of the upwelled water reaching the surface is the expulsion of fishes like oilsardine and mackerel from the vicinity since the same is highly oxygen deficient.

Whitebait

The studies conducted by the erstwhile Pelagic Fisheries Project revealed that the whitebait stock along the southwest coast of India consisted of several *Stolephorus* spp. of which *S. heterolobus* and *S. bataviensis* were the most abundant. *S. zollingeri* may be quite abundant, particularly in the northern part of the project area. It was found that the main spawning was confined to the period before and after the southwest monsoon season. Greatest abundance of whitebait larvae was observed in the Premonsoon period. Whitebait was recorded mostly in areas with bottom depth between 10 and 50 m and only occasionally in deeper waters. They exhibited a typical diurnal migration. During day time the concentrations were distributed close to the bottom while during night they were found dispersed in mid water. Distinct seasonal migrations were observed. In November-December the whole stock is spread along the southwest coast. In April a southwest movement begins and by July-August the stock is accumulated in the Gulf of Mannar. After the Monsoon the whitebait again dispersed along the coast north of Quilon in September-October.

It is possible that whitebait makes the southerly migration during June-July mainly to avoid the comparatively high temperature (above 28°C) prevailing in the Ratnagiri-Karwar region. When they reach further south the effect of the low temperature upwelled water possibly drives it further south and later towards southeast where comparatively favourable temperature (between 24° and 27°C) prevailed. The fishing results of the '*Sardinella*' and '*Rastrelliger*' revealed that during the period June-October the fish remained in the area between Cape Comorin and Tuticorin in dense concentration extending from the surface to the bottom. The setting up of the northerly current with the Post-monsoon conditions prevailing along the southwest coast namely the plankton bloom which followed the upwelling and the gradual rise in temperature resulting from the recession of the upwelling process provided the fish with favourable environmental conditions to commence their northward spreading along the southwest coast (PFP Report 1976).

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