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SEASONAL VARIATIONS OF THE OCEANOGRAPHIC CONDITIONS OFF THE SOUTHWEST COAST OF INDIA DURING 1971–1975

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ABSTRACT

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As part of a survey of the coastal fish resources off the southwest coast of India, the UNDP/FAO (United Nations Development Programme/Food and Agriculture Organization) Pelagic Fishery Project, Cochin, collected environmental data from June 1971 through October 1975. Based on these data, the oceanographic conditions during the 4–year period are discussed. The seasonal variations are highly repetitive from year to year. An uplift of water onto the shelf begins in March or April. Associated with a south-flowing current, this type of upwelling lasts throughout the SW monsoon period until September–October. A northflowing coastal current from November–December through January–February is associated with an influx of low-salinity water from the south. The environmental variations on the shelf are reflected in seasonal biological events.

INTRODUCTION

Several authors have reported on the environmental conditions along the southwest coast of India. In 1957 RAMA SASTRY and MYRLAND (1960) observed upwelling on the shelf, while BANSE (1959) described associated low values in dissolved oxygen and discussed its effects on the catch of demersal fish. Major contributions from DARBYSHIRE (1967) and BANSE (1968) established that upwelling takes place during the SW monsoon period, May–October. Due to a minimum in the oxygen distribution at intermediate depth, water with less than 0.5 ml O_2/l comes up on the shelf during the upwelling period. The south-flowing current transports Arabian Sea Water of high salinity southward along the coast, though during the rainy season runoff causes a significant lowering of the surface salinity in the coastal zone. In the NE monsoon period the current reverses, advecting less saline Equatorial Surface Water from the equatorial region and Bay of Bengal northward (DARBYSHIRE 1967, WYRTKI 1973), causing a sinking or retreat of the Arabian Sea Water.

The present paper describes some features of the hydrography off the southwest coast of India, based on a programme carried out by the UNDP/FAO Pelagic Fishery Project in Cochin. An element of this programme was the study of the relationship between environmental factors and the abundance, distribution and migration of fish resources along the coast. For this purpose the shelf region between 7 and 17°N was surveyed 7–8 times per year from the middle of 1971 to October 1975, and hydrographic sections were worked across the shelf from Ratnagiri in the north to Tuticorin on the south coast (Fig. 1).

The project presented its results in progress reports which had only a limited distribution. In the oceanographic community there is, however, a general interest in the oceanographic effects associated with the monsoon, which calls for a wider distribution of these findings. The results presented here are based mainly on Progress Report no. 16 (ANON. 1976) and partly on Progress Reports nos. 3, 7, 12, 13 and 17 (ANON. 1973, ANON. 1974, ANON. 1976 a, ANON. 1976 b, ANON. 1976 c), and presents a brief overview of the findings.

OBSERVATIONS

A total of 1500 Nansen casts with observations of temperature, salinity and dissolved oxygen were carried out from June 1971 to October 1975 in seven sections, as indicated in Fig. 1. During 1971 and 1972, salinity was determined by the classical titration method. However, from 1973 onward, an Auto-lab salinometer was used. A quality analysis of the temperature and salinity data in a T–S diagram revealed an exessive scatter in the salinity determination done by titration in 1971 and 1972. These data were therefore rejected in most of the present analysis. The Winkler method was used for oxygen determination.

Plankton was sampled by oblique Bongo net tows. BCF Bongo–20 nets (20 cm diametre) with 0.5 mm mesh size and calibrated flow meters were used.

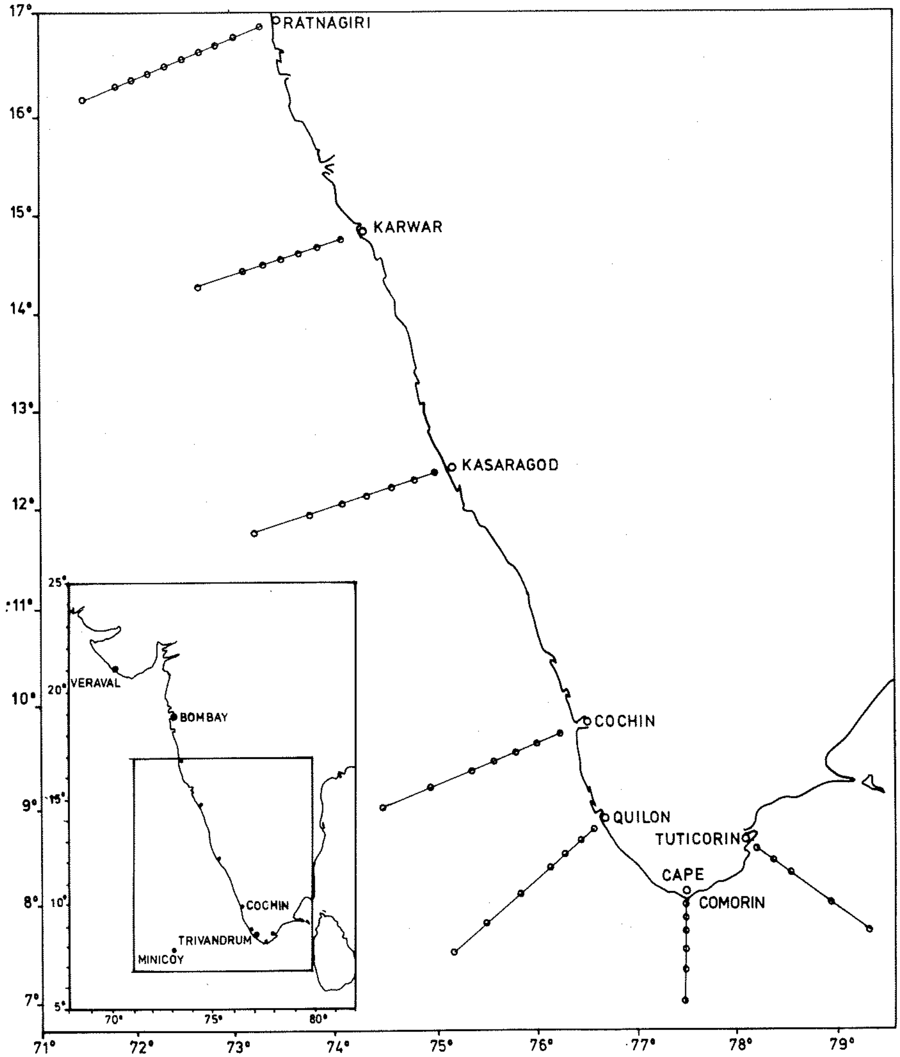

Fig. 1. Standard sections.

On the shelf the vertical range of sampling was from near the bottom to the surface and at offshore stations between the top of the thermocline and the surface (ANON. 1974, GEORGE 1976).

Assessments of the fish resources were based on acoustic surveys of the area with course tracks as indicated in Fig. 10. In the application of this method, calibrated echo sounders were used to record the fish, and the density of the resources was obtained by echo integration as described, for example, by JOHANNESSON and MITSON (1983). Trawl hauls at the bottom or in mid-water were made for biological sampling and identification of echo recordings.

WATER MASSES

RAMAMIRTHAM and PATIL (1965) and DARBYSHIRE (1967) have defined three water masses in the area. The T–S diagram in Fig. 2 for the 1974 Kasaragod section confirms the presence of these water masses. Indian Ocean Equatorial Water is found at temperatures below 17°C, and its boundary is associated with a minimum salinity of 34.9‰. The Arabian Sea Water is defined by temperatures between 17 and 26°C, the high temperature being associated with a maximum in salinity up to about 35.5‰ (DARBYSHIRE 1967). According to Fig. 2. Arabian Sea Water attains temperatures up to 28°C with associated salinities close to 36‰. Equatorial Surface Water is characterized by a small temperature range between 26 and 30°C, and a wide salinity range between 30 and 34‰. In addition, a brackish water mass associated with runoff, of salinity less than 30‰ is present in Fig. 2. The T–S diagrams for the Kasaragod section for the other years show the same pattern.

A good correlation has been established between the depth of the thermocline and oxycline (Fig. 4). This has also been observed by other investigators, for example, BANSE (1968). The T–O_2 diagram for the Kasaragod section during the four-year period is plotted in Fig. 3. It shows that below the thermocline, which during the SW monsoon terminates at approximately 21–22°C, the majority of the observations of dissolved oxygen concentration are below 1 ml O_2/l. Similar diagrams have been plotted for the other sections, eastablishing the same relationship for the entire shelf area.

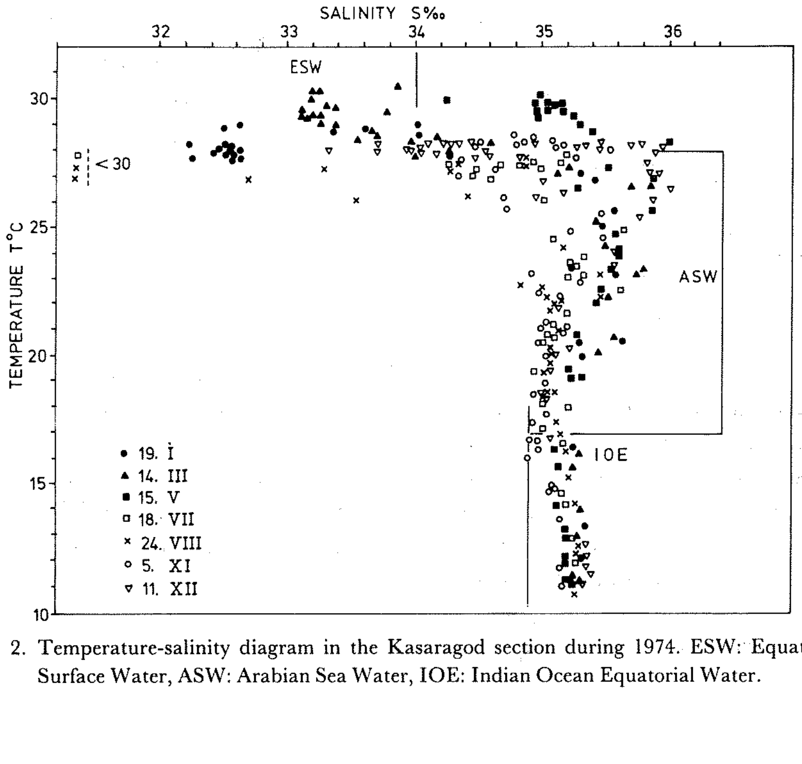

Fig. 2. Temperature-salinity diagram in the Kasaragod section during 1974. ESW: Equatorial Surface Water, ASW: Arabian Sea Water, IOE: Indian Ocean Equatorial Water.

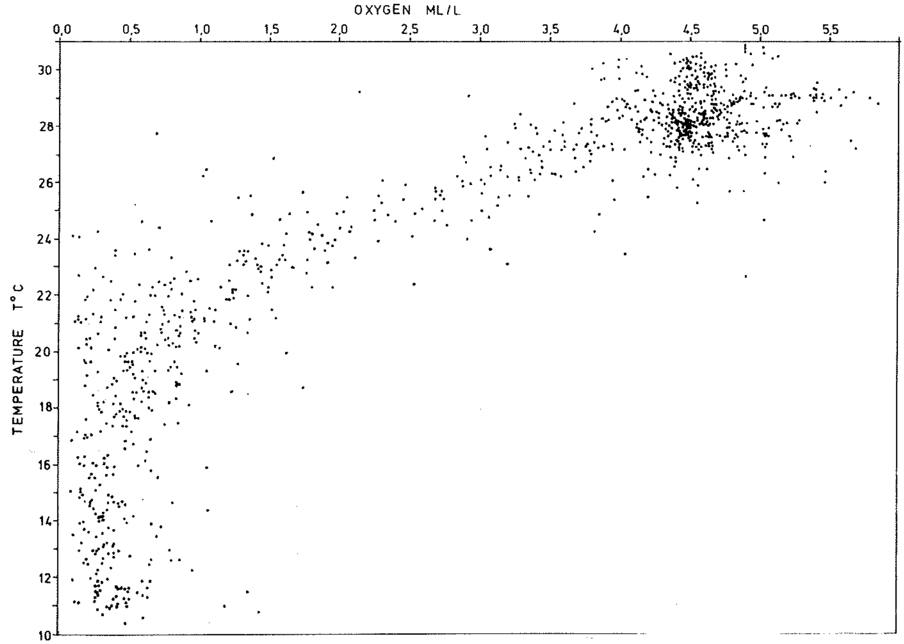

Fig. 3. Temperature-oxygen diagram in the Kasaragod section for the period 1971–1975.

SEASONAL VARIATIONS

A study of all the sections shows that the seasonal variations reported by previous authors are very dominant. Typical conditions on the shelf are, for example, described by the Kasaragod section during 1974. (Fig. 4). The density field in January indicates weak currents, but the salinity in the upper 50 m is below 33‰. This is the lowest salinity of all sections in the year and indicates presence of Equatorial Surface Water. As described for instance by WYRTKI (1973), a branch of the NE monsoon circulation flows north along the west coast from November to January, carrying this low-salinity water which originates in the Bay of Bengal. The upper-layer salinity maximum is at the 150 m level, which is typical for the tropical oceans, and the water on the shelf is well aerated.

The situation in March demonstrates a shoreward shoaling of the isopycnals over the shelf, indicating a southward flow, but in the offshore part of the section there are clearer indications in the density field of a north-flowing current than in January. The salinity in the upper 50 m layer has, however, increased an suggests a retreat of the Equatorial Surface Water or an increased admixture of more saline Arabian Sea Water. The waters on the shelf are still aerated.

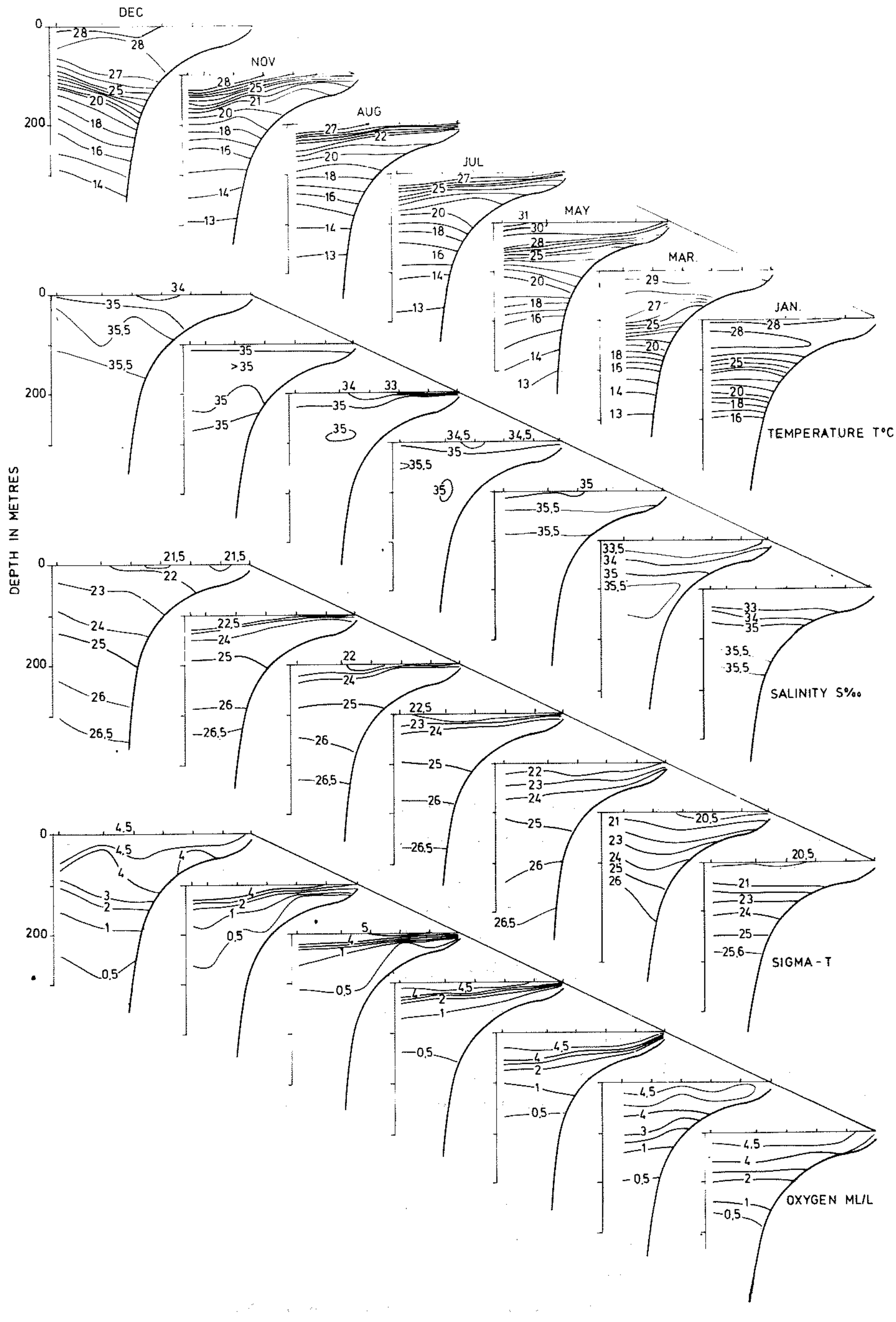

Fig. 4. Typical seasonal hydrographic fluctuations off the southwest coast as observed in the Kasaragod section during 1974.

From May through November, during the SW monsoon period, the mean flow continues southward in the upper layer. Upwelling of the Arabian Sea Water, of salinity higher than 35 ‰, is the dominant process during this period. This is illustrated by the lifting of the isotherms, with a shoaling and sharpening of the thermocline, and the penetration of the low oxygen water of less than 0.5 ml O_2/l over the entire shelf. Another feature is the lowering of the surface salinity in the nearshore region associated with the runoff during the rainy season in the SW monsoon period. This is indicated by the July and August sections.

From November to December a dramatic change in the dynamics occurs. The current reverses in the course of a month. In December it is established as a deep-reaching north-going coastal flow, thereby completing the annual cycle and again transporting low-salinity, well aerated Equatorial Surface Water northward. A rapid sinking of the Arabian Sea Water takes place during this period, suggested by the descent of the thermocline and oxycline.

SURFACE LAYER VARIATIONS

The seasonal variations in the temperature and salinity of the surface layer are illustrated in the isopleth diagrams in Fig. 5. The Cochin section was chosen for a comparison with a similar salinity diagram by DARBYSHIRE (1967, Fig. 28) for the 1958–59 period. Fig 5 shows a more repetitive pattern of the seasonal variation from year to year than could be demonstrated by the short series studied by DARBYSHIRE, who concluded that «the two years showed very different conditions and no conclusions could be drawn».

The surface salinity is low during the rainy SW monsoon period with a minimum in July–August. For example, the 33‰ isohaline extends to a maximum distance of about 60 miles off the coast in 1973. At the 10 m level the effect of runoff is drastically reduced. Generally, the surface salinity is less than 30‰ in the near-shore region from Cochin and northward, while the salinity is above 34‰ south of Quilon as illustrated in Fig. 6. Although this higher salinity in the southern region at least to some extent may be explained by the small amount of runoff in this area, the nearshore salinity front between Cochin and Quilon is suggestive of no nearshore, south-flowing current in this area. The salinity distribution in Fig. 6 suggests an offshore diversion north of the front.

The 1974 situation in Fig. 5 shows that the appearance of low-salinity Equatorial Surface Water in November or December may be rather abrupt, and the same situation shows a slower retreat in March–April. This is associated with the reversal of the current and may indicate a shorter reversal time after the SW monsoon than in March–April. In spite of considerable differences in this respect between individual years, the figure suggests that

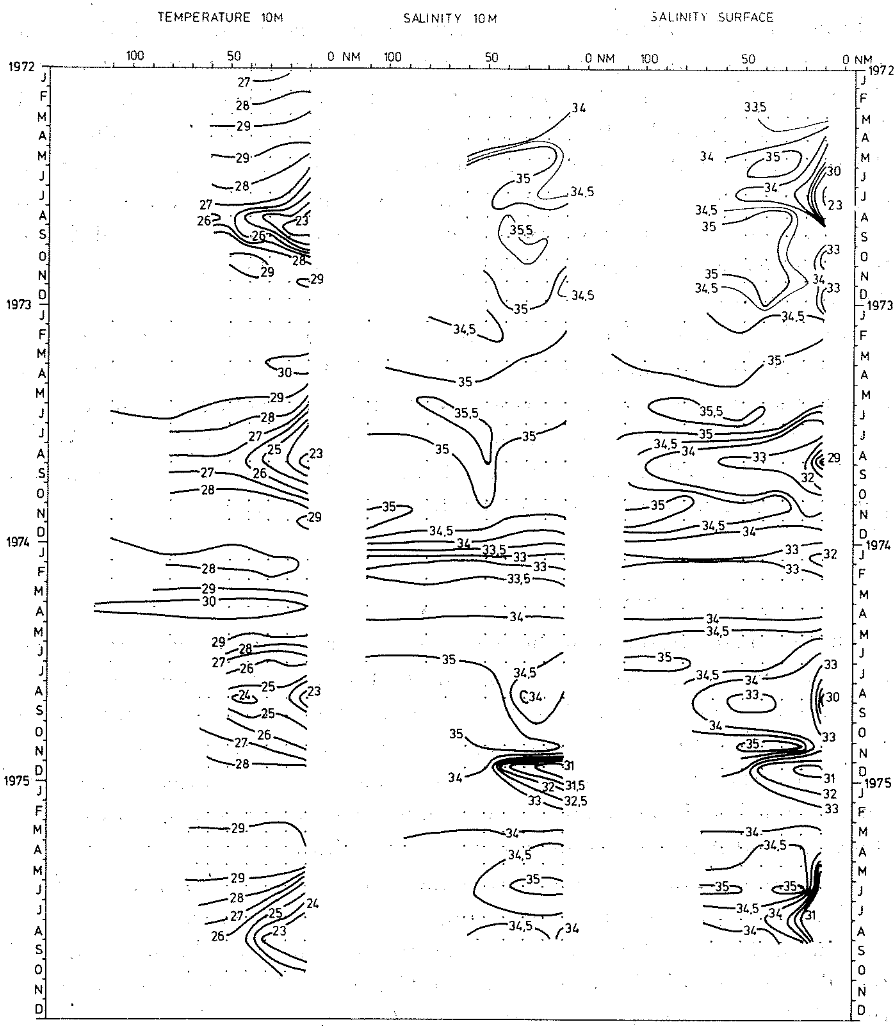

Fig. 5. Isopleth diagrams for the Cochin section; temperature at 10 m and salinity at 0 and 10 m depths. Distance from the coast in nautical miles.

this may be a general feature, but occuring to a varying extent from year to year.

The density distribution in the Kasaragod section for December 1974 (Fig. 4) shows a wedge-formed coastal current flowing northward. The considerably lower nearshore salinities off Cochin in the same period strengthen such a distribution, typical for a freshwater–induced coastal density current, theoretically described for example by HEAPS (1972). In this case, the influence of nearshore low-salinity water may therefore be a driving force. The wind field

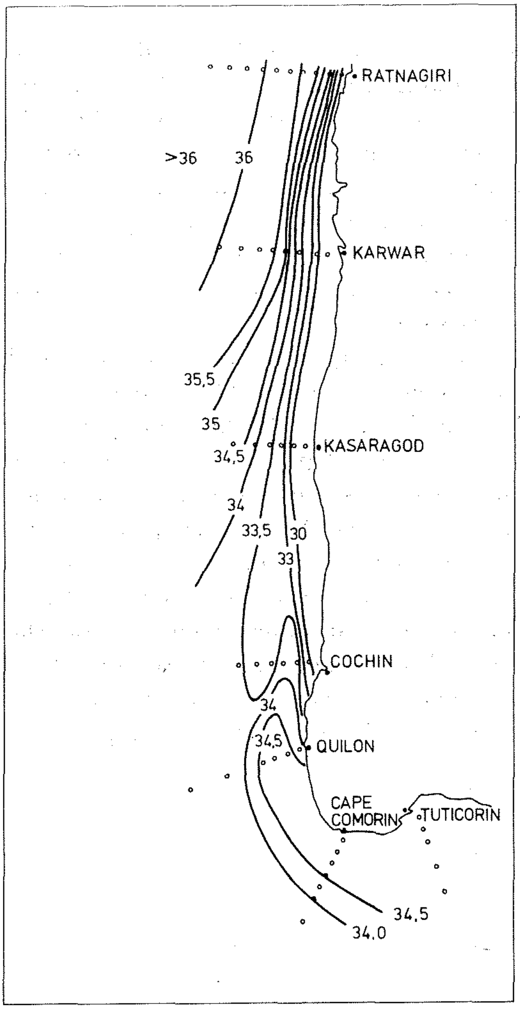

Fig. 6. Surface salinity in August 1974 illustrating the effect of runoff.

over the area is, of course, also of importance, and the interannual variations indicated in Fig. 5 may be associated with variations in supply, or properties of Equatorial Surface Water or monsoonal fluctuations.

The upwelling process during the SW monsoon is not well indicated in the surface salinity diagram of Fig. 5, but is well documented in the temperature pattern. The nearshore temperature is reduced to less than 23°C, while the offshore temperature at the same time is several degrees higher. A similar pattern develops in the oxygen values (not shown in the figure), where the concentrations are less then 0.5 ml O_2/l near the coast.

UPWELLING

Upwelling was demonstrated by the shoreward lifting of the isolines in the description of the Kasaragod section during 1974. The other sections along the coast, as indicated by the August situation for 1974 (Fig. 7), show that these features are most prominent in the Cochin and Kasaragod sections. Slightly less upwelling is observed in the Karwar and Ratnagiri sections, while a significant change occurs between Cochin and Quilon, where only the outer part of the shelf is covered with water of less than 1 ml O_2/l. This develops further off Cape Comorin and Tuticorin where the same isoline retreats beyond the edge of the shelf.

The time variability of the upwelling along the coast is illustrated in Fig. 8A, where the intersection between 1 ml O_2/l isoline and the bottom has been plotted for the Karwar, Kasaragod, Cochin and Quilon sections. Generally, the intersection is at its greatest depth from October or November to March or April. Then the uplifting starts and reaches its most shallow position within the period from July to October. A plot of temperature, up to January 1973, near the bottom at 50 m depth in the sections (ANON. 1973) indicated a northward delay of the occurence of the upwelling. This is not evident in Fig. 8A, and it is concluded that upwelling on the entire shelf starts within a period of 1–2 months. The sinking or the retreat of the 1ml O_2/l isoline from the shelf indicates the decay of the south-flowing current and the onset of the north-flowing current. In 1973 and 1974 this took place first in the southern

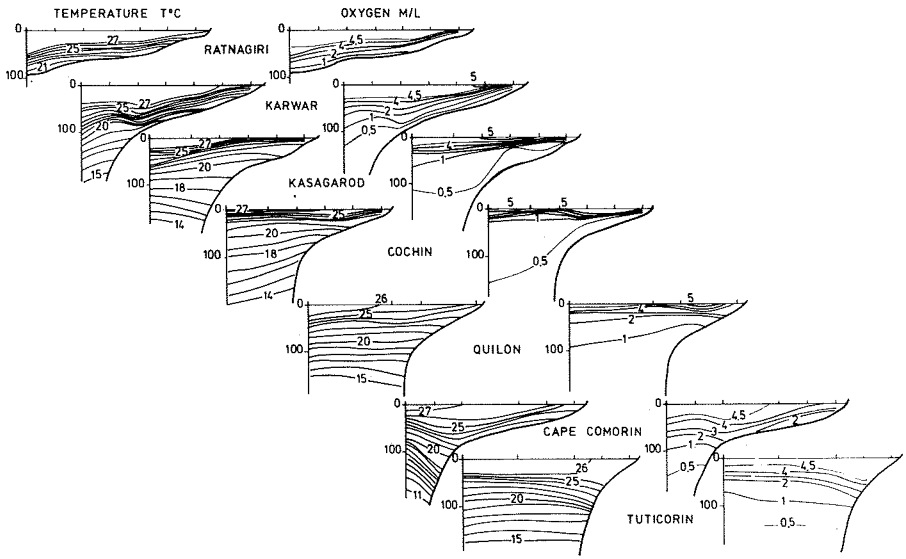

Fig. 7. Upwelling along the coast in August 1974 illustrated by the temperature and oxygen (O_2 ml/l) sections.

area off Quilon and Cochin, 1–2 months earlier than the northern area, while in 1972 it occurred at approximately the same time over the entire shelf area. The «rate» of upwelling can be qualitatively indicated by the rise of the isolines for the different parameters, which for this coastal zone is on the order of 1.5 m/day.

The driving forces of the upwelling are not evident. Several investigators have discussed the matter, and different viewpoints have been formulated. DARBYSHIRE (1967) concluded that «wind upwelling can not take place as the prevailing winds are onshore from west or southwest in the SW monsoon period» and claimed that the upwelling or the upward slope of the density surfaces toward the coast was consistent with the observed southerly current. BANSE (1968), however, mentioned that upwelling started with the onset of the SW monsoon. The interpretation of the present data suggests that the wind becomes the important driving force when the influence of the low-salinity Equatorial Surface Water decays in February. The direction of prevailing winds in February and March is mainly between northwest and northeast, of average Beaufort 3 (ANON. 1979). This gives rise to the reversal of the current system well in advance of the SW monsoon period. During the SW monsoon period the prevailing wind direction is from west (ANON. 1979, RAMAGE 1969) and is consequently not in favour of intensifying a wind-driven upwelling. Due to higher wind force during this period, the south-flowing current is, however, speeded up and the associated tilt of the isolines is increased. It seems, therefore, likely that the upwelling is not only associated with the local wind, but also with the more large scale monsoonal conditions which drive the anticyclonic Arabian Sea monsoon gyre.

OCEANOGRAPHIC INFLUENCE ON THE BIOMASS

In a discussion of the relationship between oceanographic factors and distribution and abundance of biomass, upwelling stands out as a dominant feature. Upwelling boosts the phytoplankton production in the area. This is reflected in the zooplankton production (ANON. 1976 c). The general trend of zooplankton biomass shown in Fig. 8B follows the pattern of the upwelling in Fig. 8A. On higher levels in the food chain the project observations do not reveal such close correlation with environmental components, but nevertheless upwelling is indirectly of importance since the feeding and growth of the fish population depend on the primary and secondary production.

The behaviour and distribution of some fish species are also directly restricted by the upwelling onto the shelf of cool, oxygen-deficient water. It was well known among local fishermen that schools of mackerel (*Rastrelliger kanagurta*) and sardines (*Sardinella spp.*) were often visible on the surface just before and after the SW monsoon. The investigations of the Pelagic Fishery

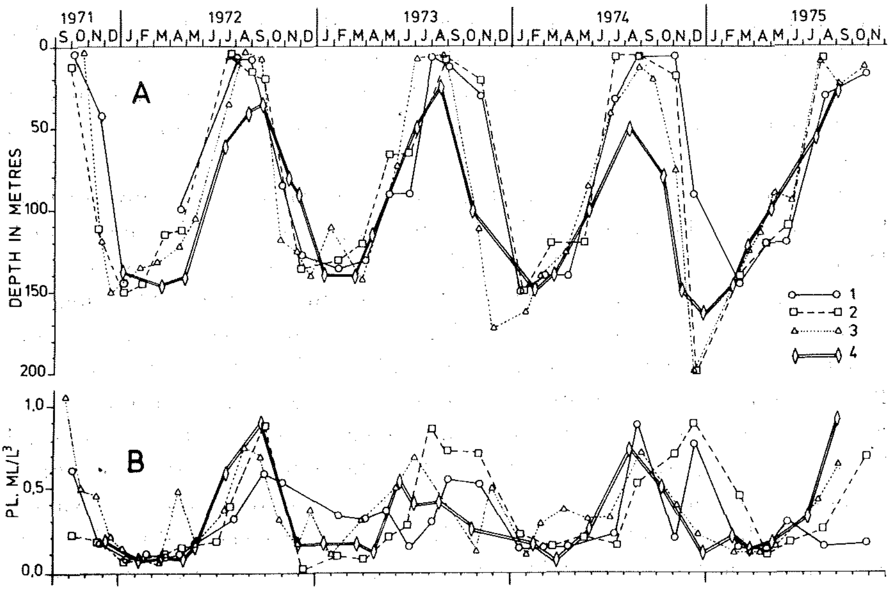

Fig. 8. A: Depth of the intersection between the 1 ml O_2/l isoline and the bottom.
B: Zooplankton biomass in ml plankton per m^3 of water filtered.
1: Karwar section, 2: Kasaragod section, 3: Cochin section, 4: Quilon section.

Project revealed that a stock of these species was present in the area also during the monsoon months, but even though the schools were not visible on the surface during the rougher weather conditions of the monsoon, they occured in the aerated surface layer above the oxycline (ANON. 1976 b).

A stock of anchovy (*Stolephorus spp.*) showed migrations clearly phased with the monsoon (ANON. 1976 a). As depicted in Fig. 9, the anchovy stock was dispersed along the southwest coast during the NE monsoon, mainly north of Quilon. A southward migration started around April–May, and in August through October almost all the stock was concentrated in the Gulf of Manaar to the east of Cape Comorin as shown in Fig. 10. The figure also shows typical survey tracks on which the distributional mapping was based. After the SW monsoon the anchovy again dispersed along the west coast of Quilon.

As previously described by, for example, GEORGE (1958) and BANSE (1959), some demersal species disappear from the oxygen-deficient water on the shelf during the SW monsoon. The Pelagic Fishery Project observed the demersal species as part of a group consisting of a considerable variety of species. Due to the different migration patterns of various species, it was difficult to draw any conclusive picture of their overall migratory behaviour. Nevertheless, the general trend was that demersal fish occurred in abundance on the northern shelf during post-monsoon months while they were concentrated on the southern shelf area during the SW monsoon months.

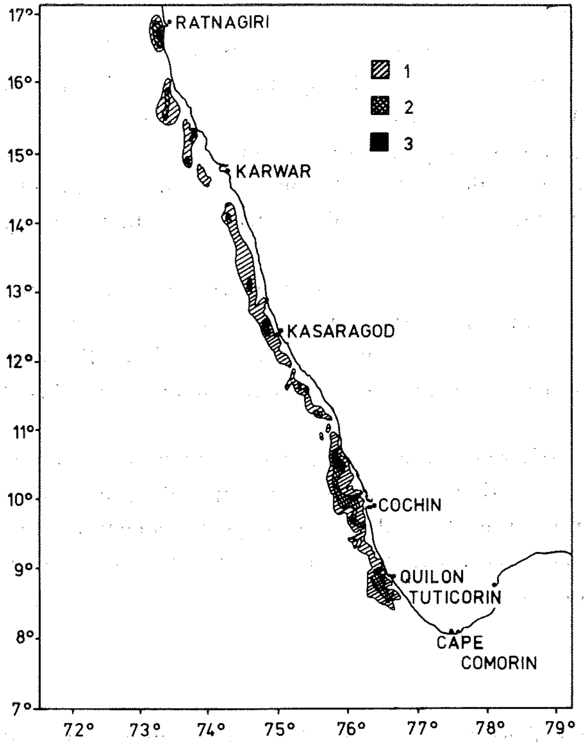

Fig. 9 Distribution of anchovy *(Stolephorus spp.)* in March–April 1974. 1: very scattered, 2: scattered, 3: dense.

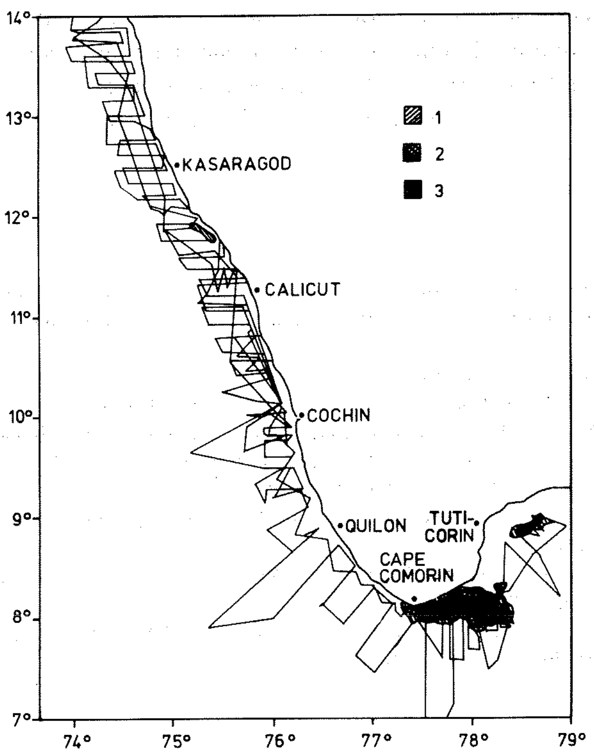

Fig. 10. Distribution of the anchovy in September–October 1974 at the end of the SW monsoon. 1: very scattered, 2: scattered, 3: dense.

SUMMARY AND CONCLUSIONS

The seasonal variations in the oceanographic conditions are repetitive from year to year. Generally, a shoreward lifting of isopleths starts in March and continues through the SW monsoon, reaching a maximum in August or September. This upwelling causes the penetration of low-oxygen water over the entire shelf north of Quilon, while south of Quilon it is less significant. The influence of runoff during the latter part of the SW monsoon can be traced up to 60 nautical miles offshore.

During the early part of the NE monsoon the current reverses. Due to the influence of low-salinity Equatorial Surface Water, this has the typical features of a coastal density current, opposing northerly winds of Beaufort 2–3. The characteristic time scale for reversing the circulation on the shelf is of the order of 1–2 months.

Some biological events clearly reflect the seasonal environmental variations. A peak in the plankton concentration is associated with upwelling. Schooling pelagic fish concentrate in the surface layer due to the oxygen deficiency below the oxycline, and some species disappear from the northern part of the shelf during the SW monsoon months.

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