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INFLUENCE OF THE SENEGALESE UPWELLING ON THE BEHAVIOUR OF PELAGIC FISH SPECIES DESCRIBED BY ECHO-INTEGRATION

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INTRODUCTION

The whole continental shelf of Senegal is subject to a strong seasonal upwelling under the influence of trade winds which blow from December to May. The surface temperature which is an easily accessible environmental parameter, characterizes the intensity and amplitude of the upwelling. The upwelled water, rich in nutrients directly controls the intensity of the primary production[1]. Those variations are reflected in the abundance of pelagic fish, mainly the Sardinella sp. which represent an important part of catches on the continental shelf of west Africa. The two most exploited Sardinella sp. are located at the first level of the trophic chain and are plankton feeders during the first month of their lives. Because of that, the consequences of environmental variations are felt even faster. Later they have a more diversified regime of food, but which remains dependent on the primary production[2].

Since the analyses of climatic factors and CPUE which are used as an index of abundance, do not show any relationship between the two phenomena, it might be easier to relate observed climatic anomalies with the direct stock assessment of pelagic species. This could be done through echo-integration techniques used over the same time periods. The surface temperature calculated by remote sensing will be used as principal environmental factor, for it is the only accessible parameter regularly measured at a time range of a week. This permits a dynamic description of the upwelling and explain the distribution of abundance measured by acoustic methods.

The area of the study is limited to the continental shelf of Senegal (10 to 200 m) for the acoustic data. For the collection of surface temperatures by satellite it extends to the Mauritania and Guinea coasts. The period of the study concerns the upwelling seasons from the years 1984 to 1988.

MATERIALS AND METHODS

The techniques of echo-integration and its results

From 1983, Senegal has been equipped with a complete Biosonics equipment. The measurements were made on the RV LAURENT AMARO, and after 1985, on the RV LOUIS SAUGER. Throughout the surveys sub-surface temperatures were continually recorded with a thermograph. The results of the acoustic measurements treated within the frame work of this study were obtained from two types of surveys: one along the whole coast, called "ECHOSAR" and any other from Dakar to the North of Gambia called "Petite Côte". These surveys were carried out on a series of latitudinal transects separated by a distance of five nautical miles. The bathymetric zone covered extends from 10 to 200 m, thus determining the length of the transects.

The values directly produced by the integrator for every sequence are given in kg/m^3. In every sequence there are a number of ranges sampled entirely or partially according to bathymetric variations. For these surveys, fifteen ranges

are determined. The computer allows us to directly gather data coming from the integrator and from SAT-NAV (for instance, the positions and speed of the vessel). Depth is determined manually. As for the temperature, it is recorded at the time of the correction of the data, modified by bottom integration, surface sound or plankton. From the data, three patterns of processing the data are made, all three taking a transect as a unit. Densities calculated in tonnes per square mile are given for every sequence of the transect.

The satellite data and their treatment

The variability and the structure of the environment can be described during the upwelling season thanks to regular mapping of the sea surface temperature. Remote sensing is adequate for such a study on the west African coast, where the lack of clouds in the atmosphere permits a high frequency of observations. The large repetition of observations of the geostationary satellite, METEOSTAT II, its sufficient spatial resolution and its thermal resolution of 0.5 degrees, allows the mapping of the sea surface temperatures with a precision and a regularity much superior to any available classical method. The processing of the satellite images can be summarized as follows: the atmospheric disturbing factors are generally sufficiently variable in time and space to be minimized using a synthesizing process of the image maximum thermic, point by point, during a period of 5 to 7 days. The information contains in each point only the signals least disturbed by the atmosphere. The images are corrected using data from merchant ships. Data of sea temperatures can be treated for each week during the years 1984 to 1986, covering the periods of acoustic survey.

RESULTS

We describe in chronological order, by year, and distinguishing two ecological areas: the northern coast from Cap Vert to Saint Louis in Senegal and the southern coast from Cap Vert to Cap Roxo (Fig. 1), for which the enrichment processes are different, especially for weak winds [3]. Table 1 shows the distribution of the survey cruises which have been used, as well as the data of the thermal synthesis which were used for the comparison of the spatial relationships between biomass and temperature.

Table 1 The distribution of survey cruises and thermal synthesis

	January	February	March
1984			....
1985	___...		
1986		.....	
1987		....	
1988		....	

Legends: .... acoustic survey periods
____ distribution of the thermal synthesis used.

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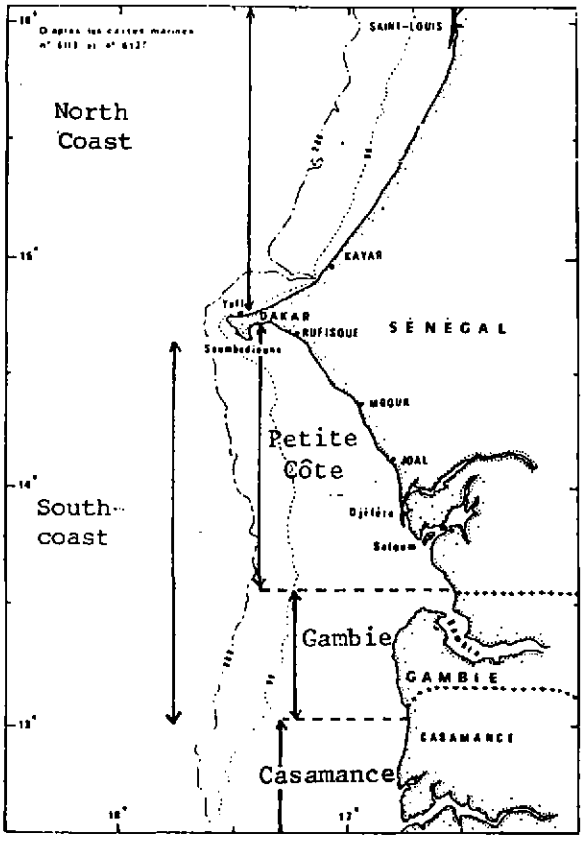

Figure 1 Area and topography of the study.

Cruise ECHOSAR 6 (7-21 March 1984)
Hydroclimtic environment and interpretation The month of January and approximately until 2 February is a period characterized by a strong upwelling along the whole Senegalese coast due to the continuous trade winds during this period. These conditions are shown by the thermal synthesis which shows the spatial extension of the upwelling. On the contrary, the month of February is characterized by a long relaxation phase of the upwelling, especially on the southern coast (la Petite Côte). The stable situation which follows and which is associated to weak vertical movements, is favourable to a strong superficial phytoplankton development. This warning phase starts already at the beginning of February and progressively continues during the whole month.

(a) Northern coast: The upwelling along the northern coast decreases continually from the beginning of February and does not increase until the beginning of March (during the survey). The coldish area (approximately 19°C) is

located around Saint Louis where most of the important concentrations have been found (Fig. 2).

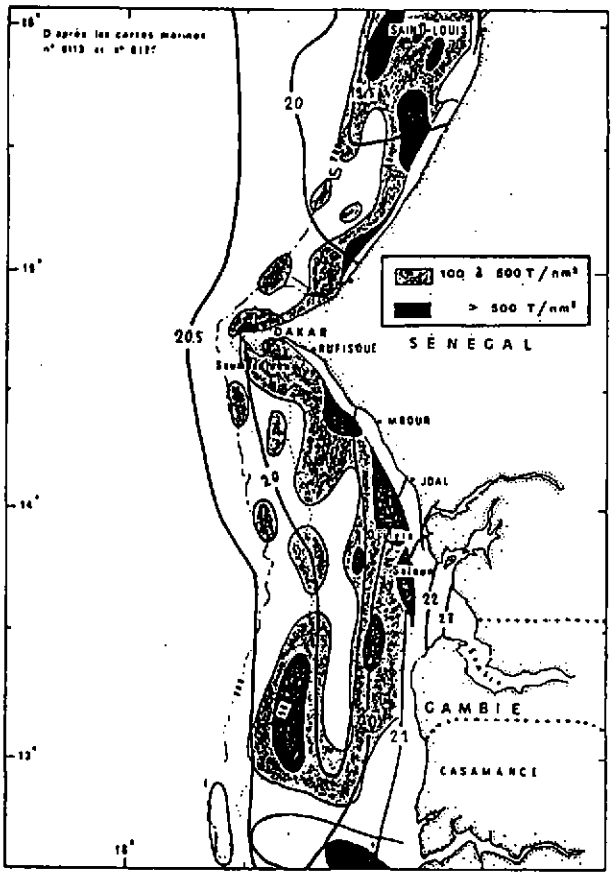

Figure 2 Distribution of fish density and thermal synthesis (7-12 March 1984).

(b) Southern coast: The upwelling clearly resumed again at the beginning of March on the southern coast and quickly increases during two weeks after which it remains stationary until April. The survey along the southern coast takes place on 12-21 March. Two CZCS images of the distribution of chlorophyll pigments from 16-25 March shows a fast decrease in the rich coastal area, well characterized on the previous months images (Fig. 3). This area, rich in chlorophyll and already very limited along the coast around the 30 m isobath, completely disappears on 25 March.

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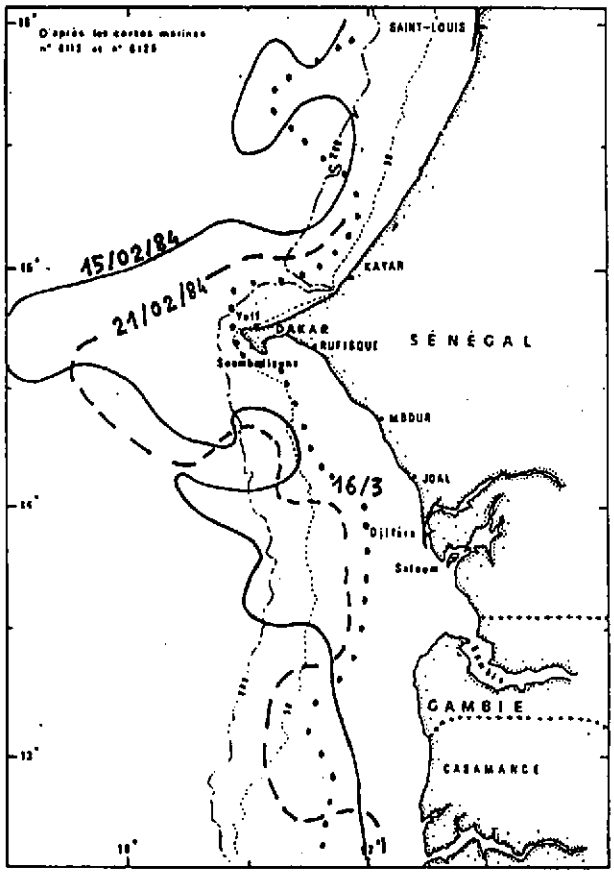

Figure 3 Limits of concentration in chlorophyll a (< 10 mg/m^3) from satellite image (February 1984)

As a conclusion, the month of February 1984 shows a positive temperature anomaly in the middle of the cold season, which leads to exceptional conditions for the plankton development.

The areas close to the upwelling periphery have thus taken advantage of the enrichment and also of the relative stability of the surface waters. The high densities of fish have been found on one hand on the southern coast in shallow waters between Mbour and north of the river Saloum (sardinella schools at depths of 10 to 20 m) and on the other hand in front of the north of the river Casamance (Fig. 2). Sardinella schools have also been detected off the Gambia at depths of 50 m. A synthesis of the surface temperatures measured

continuously during the cruise and of the temperatures obtained from the satellite images permits a precise localization of the upwelling extension during the cruise. It shows that, apart from one sardinella school which was detected very near the coast in front of Mbour, the important detections on the southern coast are located almost completely outside the active upwelling area and most frequently between this latter area and coast. The observed distribution seems to depend essentially on the upwelling extension which in general seems to limit the spreading of the schools further off the shore.

Cruise "Petite Côte 3" (7-12 January 1985)

Hydroclimatic context

The month of December 1984 is characterized by a very weak upwelling on the "Petite Côte" appromixately until 26 December. The week from 27 December to 2 January shows an upwelling activity (mean anomaly on the "Petite Cote": 2,5°C),

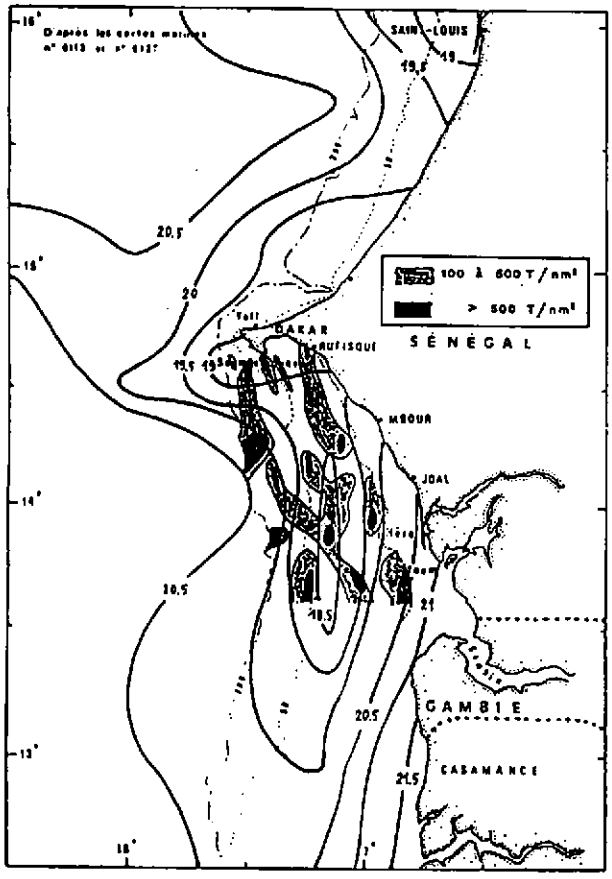

Figure 4 Distribution of fish density and thermal synthesis (7-12 January 1985).

which slightly increases on 12 January and extends to the south, remaining however very little extended further offshore. The map of the surface temperatures continuously measured during the cruise shows the cold waters (temperatures below 17°C) in the shape of strips detected from the coast between Mbour and the peninsula of Cap Vert along the 50 m isobath. The satellite image of 12 January equally shows a classical upwelling linked to the coast in this area (Fig. 4). The density distribution map obtained during the cruise "Petite Côte" from 7-12 January 1985 shows that almost all the central upwelling area extending from Dakar towards the south west and later to the south, is devoid of important fish concentrations. In return the three most important concentrations observed were located on one hand south of Dakar at different depths of 100 to 200 m and on the other hand at 10 m depths in front of the north of the river Saloum. These two areas exactly correspond to those not covered by the upwelling (temperatures above 19°C) but located nearest the latter.

Biomass estimation and interpretation Despite the cruise being earlier, certain common factors can be observed when comparing the distribution of the biomass with those observed during the cruise ECHOSARV 6, 12-21 March 1984 (Fig. 4). The most important detections are mainly located outside the cold-water spots. Of these, detections are located either near the 10 m isobath or relatively warm waters (> 18.5°C) and they correspond to pelagic schools located at the edge of the continental shelf between the surface and 50 m depth. Important schools of Drachydeuterus auritus have also been observed at the cold water stream between Rufisque and Mbour.

Cruise ECHOSAR 10 (19 February to 2 March 1986)
Hydroclimatic context and interpretation (see Fig. 5)
(a) North coast (27 February-2 March) An intensification of the upwelling is observed during January (mean temperature of 17°C). A decrease is observed about 15 February, and then a normal upwelling stays during the cruise. The fish density during this time is rather low and concentrated between the coast and the 50 metes isobath, in the south region of Saint Louis (Fig. 5). A narrow relationship is observed between high density and the coldest area.

(b) South coast (19-26 February) The upwelling intensity is low during January (mean t°: 19°C), and the centre is located near the Cap Vert. This situation is commonly observed during low wind periods. The general upwelling dynamic is the same as for the north coast during February and March, and a southward displacement of the upwelling centre is observed. The greatest density of fish appears near the coast, and the general presence of the banks is limited to the peripheral part of the upwelling.

Cruise ECHOSAR 12 (13-28 February 1987)
Hydroclimatic context and interpretation (see Fig. 6)
Fig. 6 shows the repartition of the high density values of fish according to the thermal surface field during the same period.

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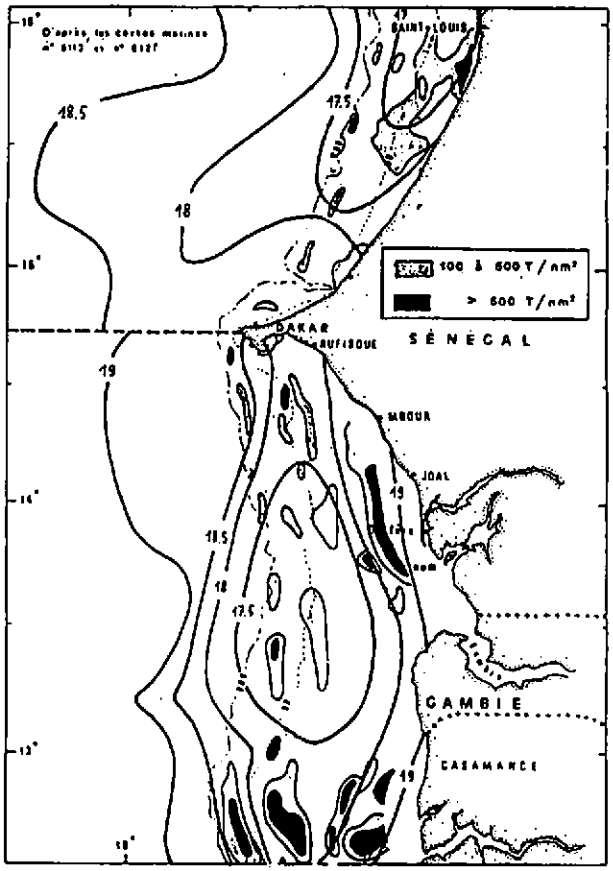

Figure 5 Distribution of fish density and thermal synthesis (19 February-2 March 1986).

(a) North coast (13-17 February) The sea surface temperature decreases strongly from January to 15 February, during the cruise (mean t° < 18°C). The highest density of fish are observed only in low depth (< 50 m) in the Saint Louis region, in the coldest area.

(b) South coast (18-28 February) The upwelling strongly decreases from mean temperatures from 17.5 to 21°C. In the same time, the coldest sea surface waters moves from north Gambia (50 m isobath) northward to the Cap Vert (Fig. 6). The maximum fish densities are in front of the rivers (Saloum, Gambia and Casamance) near the coast, and, in the west side of the upwelling near the 200 m isobath. So, high fish density is not observed in the central area of the upwelling (Fig. 6).

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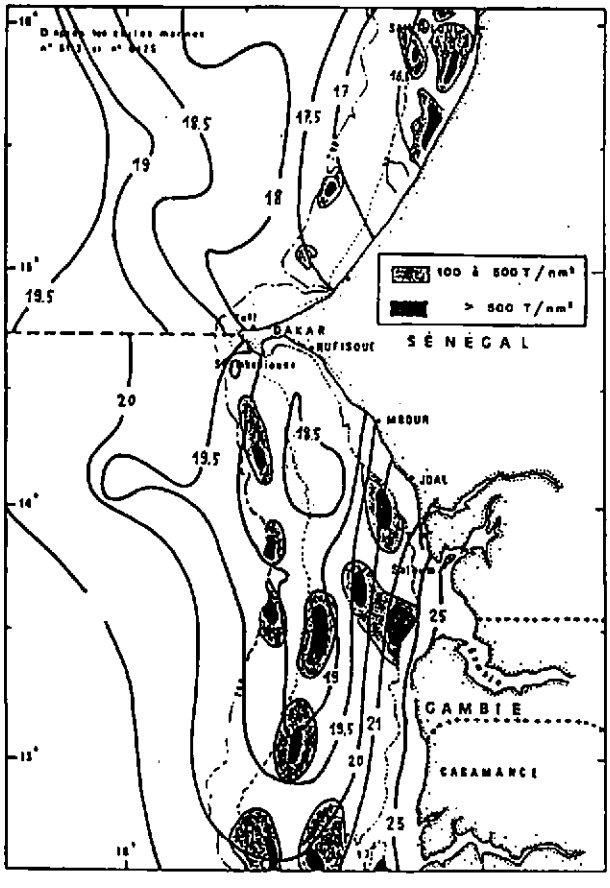

Figure 6 Distribution of fish density fish density and thermal synthesis (13-28 February 1987)

Cruise ECHOSAR 14 (13-23 February 1988)
Hydroclimatic context and interpretation (see Fig. 7)
(a) North coast (13-17 February) The upwelling intensity from January to 15 February. The mean temperature decreases from 21 to 18°C. High fish density are near Saint Louis region in the coldest area, according to the same scheme observed from 1984 to 1987.

(b) South coast (19-28 February) The upwelling intensity decreases during this time. The coldest waters are observed between Cap Vert and Gambia and progressively moves northward near the Cap Vert as in 1986. The highest density of fish are observed only in the Gambian waters on the south part of the upwelling. This is the same as observed during the past years.

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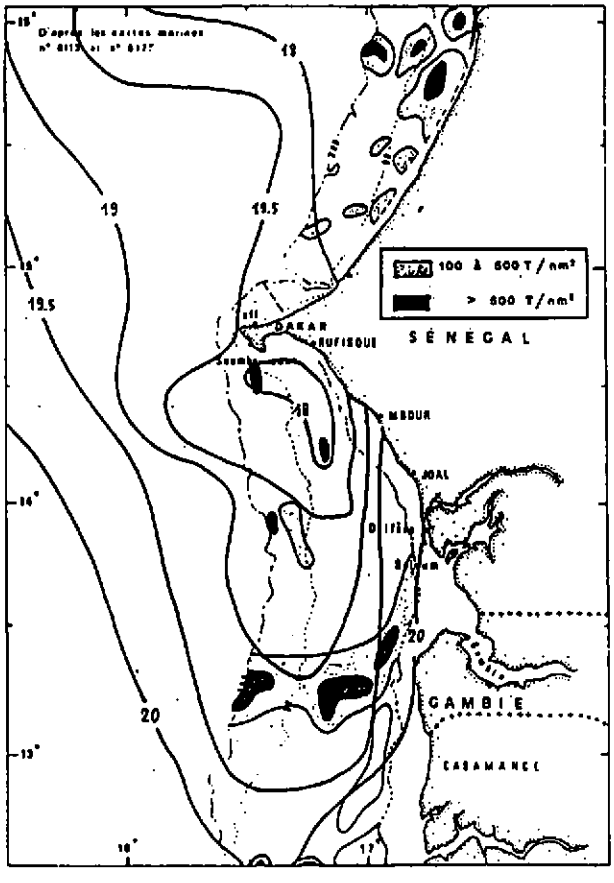

Figure 7 Distribution of fish density and thermal synthesis (13-23 February 1988).

CONCLUSION

The METEOSTAT temperature maps compared to those obtained from the acoustic surveys during the cold season show:

- on the Senegalese north coast; schools are located in the cold upwelling area
- on the Senegalese south coast; high densities of fish are present at the periphery of the centre of the upwelling.

Although we were not able to carry out controlled fishing for the identification of the important detections, two assumptions can be made.

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The species detected are different in the north and in the south and do not react in the same manner towards the cold water. Also, the detections in the north and in the south are not in the same depth range.

The environment between the north and south are not the same. The scheme described on the south coast has already been observed for the sardinella larvae[4] and by echo-integration on the Ivory Coast pelagic fish[5]. In fact, the upwelled waters are poor in oxygen and are avoided by the fish. Otherwise, primary and secondary production begin after a delay of the presence of upwelled water on the surface, thus necessarily far from the origin of the upwelling and the turbulent area. The Senegalese upwelling seems to increase the classical bias about the inherent non-uniformity of fish distribution within the survey area and the assumption concerning the environment in which we are working. This study suggests that during the cold season, it is important to consider the sources of errors due to the action of the upwelling in order to have good sampling.

REFERENCES

[1] REBERT, J. P., 1979. Hydrologie et dynamique des eaux du plateau continental senegalais. Doc. scient. Cent. Rech. Océanogr. Dakar-Thiaroye, 93, 186 p.

[2] Doman, F., 1979. Le satellite METEOSTAT et l'océanographie; Etude des températures de la mer au voisinage des côte de MAURITANIE et du SENEGAL. Télédetection 3, série IDT ORSTOM.

[3] Roy, C., 1988. Vents et fluctuation de l'upwelling devant les côtes du Sénégal. Sous presse (à paraître dans Océanologie acta).

[4] Conan, F., 1976. Distribution et abondance des larves de Sardinella aurita Val. 1847 dans la région du SENEGAL en 1974. Cah. ORSTOM. sér. océanogr. Vol. XIV, No. 3, 221-225.

[5] Marchal, E., Picaut, J., 1977. Répartition et abondance évaluées par écho-intégration des poissons du plateau ivoiro-ghanéen en ralation avec les upwellings locaux. J. Rech. Océanogr. Vol. II, No. 4, 1977.