Impact of the Northwest African Upwelling on the Migration of the *Thiof (Epinephelus aeneus)* (Pisces: family Serranidae)

The appearance of the migrant stock of the grouper fish, known as *thiof (Epinephelus aeneus)* (Pisces: family Serranidae) along the north coast of Senegal (Figure 1) is related to the onset of coastal upwelling. We analyzed the fishery data, from 1974 to 1985, in relation to coastal sea surface temperature (SST) and Ekman transport. First, the impact of this upwelling on the dynamics (migration intensity) of the *thiof* is analyzed. Then, some hypotheses are presented to explain the seasonal migration from Mauritania to Senegal.

The Senegalese coast, the northwest boundary of the African continent, is one of the most productive maritime areas of the world. The trade winds blow seasonally from the north and parallel to the coast during the winter and spring. From October through June, the resulting Ekman transport is mainly offshore and brings to the surface cold, rich subsurface waters (Wooster *et al.,* 1976). During the summer, tropical warm waters advected by surface currents from the south replace the cold and rich upwelled waters. A strong seasonal temperature cycle along the coast results from the alternation of these two contrasting water masses. The thermal amplitude of this seasonal cycle may be as large as 15°C.

Saharan fish species, occurring from July to October in the permanent cold upwelled water between 20°N and 30°N, begin to migrate toward the south in November (Champagnat and Domain, 1978). They reach the Senegalese coast around November, and occupy this area until June when the cold upwelled waters are replaced by the warm tropical waters.

From 1974 to 1985, 14–day temperature anomalies are calculated from daily, coastal sea–surface temperatures collected in Kayar, the main fishing landing point on the north Senegalese coast. From these data, an annual upwelling index is calculated by adding the 14–day temperature anomalies from October through June (Table 1). We define the beginning of the upwelling season as the maximum difference between the temperature of two consecutive 14–day periods. Fourteen–day mean seasonal offshore Ekman transport, using daily wind–speed data from 1974 to 1984, is calculated for two locations at Yoff (15°N) and at Nouadhibou (20°N).

From 1974 to 1985, catch per unit of effort of the Senegalese small–scale fishery was calculated from the fishery data collected in Kayar. Catch per unit of effort (catch per trip) and catch calculated during the fishing season (October to June) gives a measure of apparent and local abundance (Figure 2). The beginning of the fishing season is identified from the fishery data by the sharp increase of catch per unit of effort that appears when the fish arrive in Kayar.

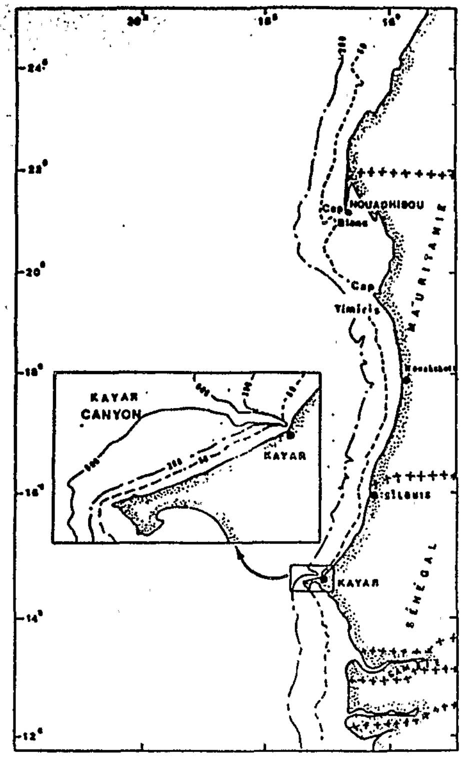

FIGURE 1 *(Cury and Roy)*
Topography of the continental margin off Sénégal and Mauritania.

TABLE 1 *(Cury and Roy)*
Annual upwelling index from 1975 to 1985 at Kayar.

Year	Upwelling Index
75	-4.58
76	-11.96
77	-3.34
78	-1.36
79	3.40
80	2.09
81	----
82	6.53
83	9.30
84	6.17
85	-7.87

The relationship between the onset of upwelling and the occurrence of *thiof* at Kayar is investigated. A mean lag of about one month (between one and three 14–day periods) is found between the onset of upwelling and the occurrence of the *thiof* at this location (Figure 3). There is no apparent relationship between the temperature measured in Kayar when the fish arrived nor one or two 14–day periods before their arrival (the temperature varies between 18 and 24°C. This agrees with the concept that the onset of the migration is due more to an ecological process (enrichment level) than to a particular thermal preferendum.

The upwelling off Mauritania is permanent between 20°N and 25°W (Wooster *et al.,* 1976). It is surprising that, if the conditions off north Mauritania are favorable all the year, the *thiof* migrates seasonally southward. In fact, the onset of the Senegalese upwelling appears simultaneously with a reduction of the upwelling off north Mauritania (Figure 4). The upwelled water in the Senegalese upwelling is composed mainly of South Atlantic Central Water, which is more rich than the North Atlantic Central Water upwelled north of 20°N. We measured the intensity of these two upwellings using the Ekman transport as an index. However, due to the different types of the upwelled water masses, we note that the enrichment is more important in the Senegalese upwelling than in the area farther north (Voituriez and Herbland, 1982). The *thiof* migrates from northern Mauritania, which is productive during all the year (but with variable intensities), to the north Senegalese coast, which is more productive during the upwelling season. This migration strategy illustrates the ability of the *thiof* to colonize the most productive areas.

At a seasonal time scale (fishing season), the form of the relationship between catch per unit of effort (or catch) and upwelling intensity is not linear but shows a dome shape (Figure 5). Strong negative or positive anomalies of temperature appear to have a negative effect on the catch per unit of effort and catch. Similar results have been found by Cayré and Roy (1985) for Atlantic tunas and by Le Reste and Odinetz (1984) for shrimp in Casamance. One of the most important conclusions of the CINECA program was that primary productivity is affected by too weak or too strong physical processes (Barber, 1982). These results applied to the higher levels of the food chain may present an interesting hypothesis to explain the non–linearity between climate and fisheries.

The results emphasize the importance of local and remote effects on fish migrations. They also point out the necessity of considering the impact of environment on fish in terms of physical processes. This means introducing only simple values but also an analysis of the variability of physical parameters.

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C. ROY

Long-term Trends and a Major Climate Anomaly in the Tropical Pacific Wind-field

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Introduction

Data from winds in the Pacific were subjectively analyzed. These data are from Florida State University (FSU), and cover the period 1961-1983. They strongly suggest that the central and eastern Pacific trade winds, both north and south of the equator, have undergone a zonal strengthening of the order of 1 ms^{-1} over that time. To validate this major change in the tropical atmospheric circulation, a subset of the ship-wind data of the U.K. Meteorological Office was used. This information provided monthly averages and observations, by five-degree squares, for the period 1920-1983 in the region (120°E - 75°W; 30°S - 30°N). Some quality control produced these monthly averages. We omitted those observations lacking either speed or direction and those which were deemed physically unreasonable *[Editor's Note: This is unexplained]*. These data were not smoothed, and hence squares with no observations were flagged *[Editor's Note: This is unexplained]*.

We present the preliminary results of a study of these data. During the period of overlap with wind data from FSU, the two data sets showed good agreement. In particular, the intensification of the tropical easterlies east of about 160°W was traceable back to 1946, and in some areas back to the 1920s. The year 1946 is important in other respects. It forms the abrupt end of a strong, decade-long westerly anomaly in the tropical circulation. During that year, we also observe a permanent increase of approximately 1 ms^{-1} in the strength of the western extension of the NE trades. Within this region of the western Pacific, both before and after the prolonged warm anomaly, there is little evidence for a gradual strengthening. In the SW Pacific, there appears to be little change in the circulation, apart from the anomaly during the 1940s, over the 64 years of records.

Analysis and Discussion

In Figure 1, a longitude-time plot of zonal velocity anomalies, averaged annually from 5°S to 5°N, is presented. The anomalies are shown with respect to a 64-year climatological record; years containing no data have been indicated by a cross-barred box. The shaded regions of positive, or westerly, anomalies highlight several features that we wish to indicate. One is the persistent, basin-wide westerly anomaly of the late 1930s to the mid 1940s. As the peak of this disturbance is from 1940 to 1945, it can be suggested that the decade-long climate anomaly is due to less-reliable observations made during the Second World War. The quality control during this period drastically reduces the ratio of the number of observations used, as opposed to those available. However, examination of those that remain, and of regions such as the central North Pacific that retain the pre-war number of observations, consistently shows the anomaly. The classification by Quinn *et al.*, (1978) of El Niño events includes the periods 1939-1941, 1943-1944, and 1946. These periods should be viewed as major climate anomalies rather than as a succession of El Niño events.

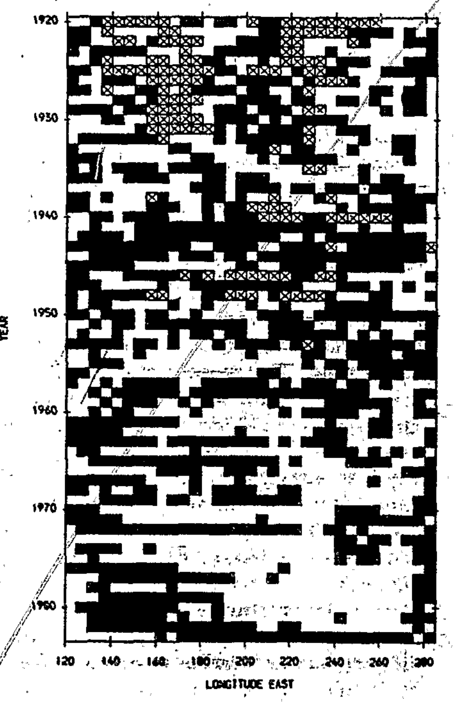

FIGURE 1 *(Bigg, Whysall, and Cooper) Longitude-time plot of zonal wind anomalies, averaged annually from 5°S to 5°N. Shaded regions represent positive, or westerly, anomalies; unshaded regions correspond to negative, or easterly, anomalies; cross-barred regions contain no data.*

The other feature recognizable in Figure 1 is the trend towards more easterly winds as the present day is approached, particularly in the central and eastern Pacific. This is seen by the large space-time area of negative, or easterly, anomalies following the persistent westerly anomaly during the 1940s.

To give a view of these features distant from the equatorial region, we present Figures 2 and 3 as time-series of 12-month running means of winds averaged over regions of the North and South Pacific trade winds, respectively. The two regions (5°-25°N, 180°-160°W and 0°-20°S, 130°-110°W) correspond to the central areas of Barnett's (1977) first empirical orthogonal function of the two trade-wind belts. The individual monthly values were calculated by averaging those 5° squares that contain data. In those months with inadequate data, the climatological average wind was used to avoid aliasing effects. The horizontal sections of Figure 3 in the late 1930s therefore mean that there were few or no observations at that time.

Both figures show the trend towards stronger easterlies after the mid 1940s, with the South Pacific (Figure 3) showing the slow increase and the North Pacific (Figure

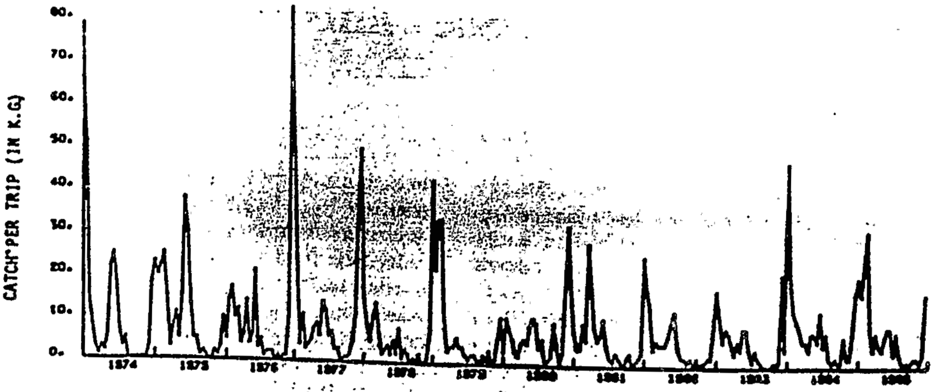

FIGURE 2 *(Cury and Roy)*
Catch per unit of effort (catch per trip) at Kayar, from 1974 to 1985.

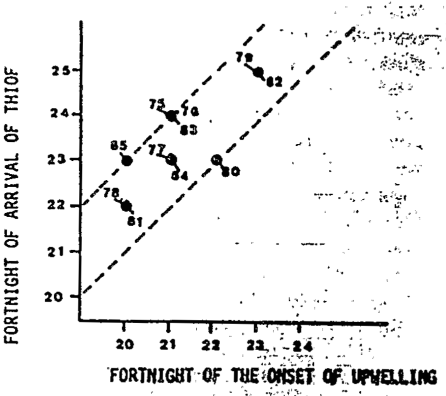

FIGURE 3 *(Cury and Roy)*
Date (fortnight = 14-day period) of the arrival of thiof *and of the upwelling onset at Kayar, from 1975 to 1985.*

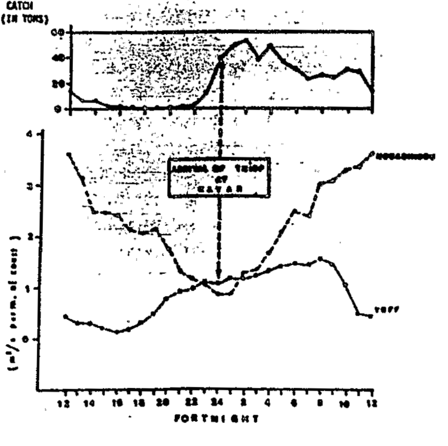

FIGURE 4 *(Cury and Roy)*
Offshore Ekman transport (m³/s per meter of coastline), at Nouadhibou and Yoff from 1974 to 1984. Mean catch of thiof *at Kayar during the same period.*

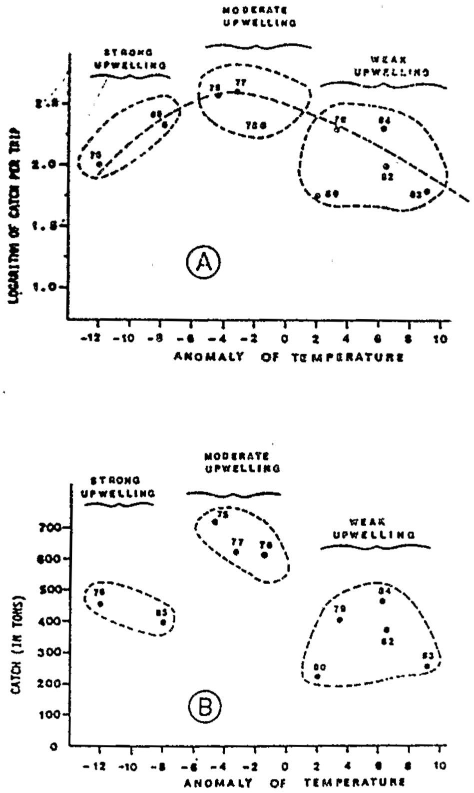

FIGURE 5 *(Cury and Roy)*
Logarithm of catch per trip (A) and catch versus temperature anomalies at Kayar (B).

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Ph. Cury
and
Cl. Roy
Centre de Recherches Océanographiques
de Dakar – Thiaroye
B.P. 2241
Dakar, Sénégal