Climate Dependent Fluctuations of the Moroccan Sardine and their Impact on Fisheries

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ABSTRACT

The Moroccan Atlantic sardine (*Sardina pilchardus*) stocks have undergone some changes of abundance and distribution range during the past five decades. A long-term increase in Moroccan coastal upwelling intensity between 1950s and mid-1970s due to an increase in trade winds intensity is suggested to have induced this long-term fluctuation of sardine. The implications for the Moroccan sardine fisheries are discussed.

RÉSUMÉ

Les stocks de sardines marocaines atlantiques (*Sardina pilchardus*) ont connu des changements d'abondance et de distribution depuis les cinq dernières décennies. Un accroissement à long terme de l'intensité de l'upwelling côtier marocain entre les années 50 et le milieu des années 70 dû à l'accroissement de l'intensité des alizés est suggéré comme ayant induit cette fluctuation à long terme de la sardine. Les implications pour les pêcheries de sardine marocaine sont discutées.

INTRODUCTION

The Moroccan Atlantic coast, extending from the Gibraltar Strait (36°N) to Cape Blanc (21°N), is one of the world's four major coastal upwelling systems. In this area, catches are composed of small coastal pelagics similar to those encountered in other coastal upwelling systems, with the difference that they are dominated by the European sardine (*Sardina pilchardus*).

Previous studies have stressed instability as an inherent feature of coastal pelagic stocks, and its dramatic consequences for the fisheries (Sharp and Csirke, 1983; Pauly and Tsukayama, 1987; Wyatt and Larrañeta, 1988; Kawasaki *et al.*, 1991; Cury and Roy, 1991; Payne *et al.*, 1992). The abundance of coastal pelagic fish stocks varies considerably in time, and there is evidence, from paleoecological studies, that major variations have occurred before the beginning of the exploitation (Soutar and Isaacs, 1974). Many authors drew attention to the remarkable similarity in long-term catches of some widely separated stocks (Kawasaki, 1983, 1992; Lluch Belda *et al.*, 1989, 1992). Long-term catch fluctuations are accompanied by changes in stocks' geographical ranges (Crawford and Shannon, 1988; Junkera, 1986; Lluch Belda *et al.*, 1989, 1992; MacCall, 1990). These major long-term changes of abundance and geographical distribution are generally attributed to climatic changes (Kawasaki, 1983; Binet, this vol.; Demarcq, this vol.).

Sardine constitutes the backbone of the pelagic fishing industry in Morocco since the 1920s. Sardine distribution have undergone some changes since the 1960s which forced the small scale fisheries to move their base of operation. Consequently, the shrinkage of the traditional fishing area had a serious impact on the Moroccan pelagic industry. This paper describes these changes and presents an attempt to explain these long-term fluctuations in sardine stocks.

1. LONG-TERM CHANGE IN THE DISTRIBUTION OF SARDINE CATCHES

1.1. Sardine distribution pattern

The Atlantic sardine is divided into three stocks along the Northwest African coast (Fig. 1): a small northern stock between Cape Cantin and Gibraltar Strait, a central stock between Cape Cantin and Cape Bojador and a southern stock from Cape Bojador to Cape Blanc.

The three stocks of Atlantic sardine off Morocco (Northern, Central, Southern) are exploited in four fishery areas (Fig. 1). For the central stock, a zone A, from Safi to South of Agadir is distinguished from a zone B, from Sidi Ifni and Laâyoune, and which is exploited by Moroccan and Canarian boats. The southern stock is exploited by the fleet from eastern Europe.

These stocks carry out seasonal migrations along the coast within the limits of their geographical range. They concentrate in spawning areas for reproduction, but spread out during the upwelling season. These movements have a minor effect on

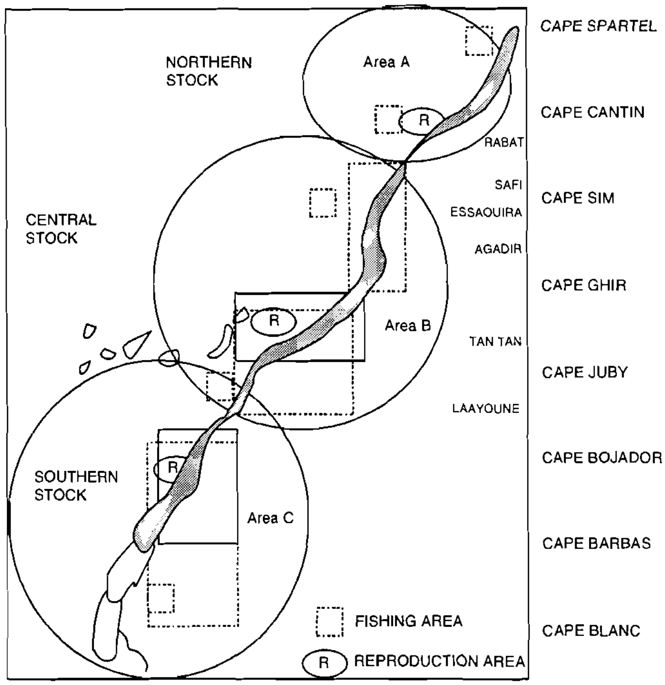


Fig. 1: Distribution pattern of the Moroccan sardine stocks and of their spawning (solid lines) and fishing grounds (dotted lines).

the central stock fisheries in areas B and for the southern stock, but they are important for the fishery in area A where the boats have a limited range of action. The availability of sardine in area A depends on the extension of the central stock that migrates every spring and summer from the southern end of the range.

1.2. Stock and catch trends

1.2.1- Brief history of the fishery

The exploitation of the Moroccan sardine developed chronologically from the north to the south. Small European fishing boats (Spanish, Portuguese and French) started fishing in the 1920s, in the areas of Larache, Casablanca and El Jadida. By the end of the 1930s, the fishery extends to Safi and Agadir. Other fisheries developed afterwards in the south. The Soviet Union fleet started exploiting the southern stock in the late 1950s, and a Canarian fishery in area B of the central stock developed in the 1960s. In the 1980s, Moroccan fisheries extended to area B of that same stock. The long-term catch of sardine along the Moroccan Atlantic coast from 1936 to 1990, is presented on Figure 2. It shows a gradual increase with peaks of great abundance in the mid-1970s and the late 1980s. As might be seen, the relative importance of the Moroccan sardine stocks increase towards the south (Fig. 3a, b, c). The central stock provides the bulk of the catch.

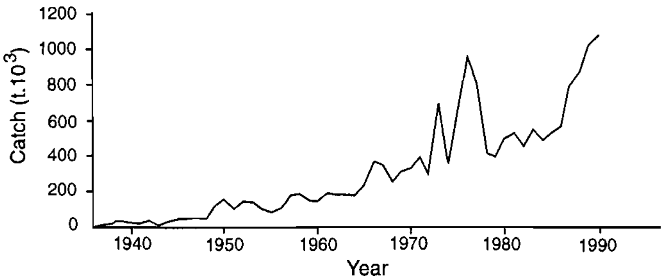


Fig. 2: Catch of Moroccan sardine along the Atlantic coast, 1936 to 1990.

1.2.2- Northern stock (Cape Spartel - Cape Cantin)

Little is known about the small northern stock. The only available information comes from catch statistics. Sardine catch decreased in the north between 1936 and 1960, probably because fishing effort moved south. This decrease was followed by a relative increase in the 1960s that strengthen during the 1970s and 1980s (Fig. 3a). One cannot, however, ascribe this increase simply to an increase in fish stock abundance.

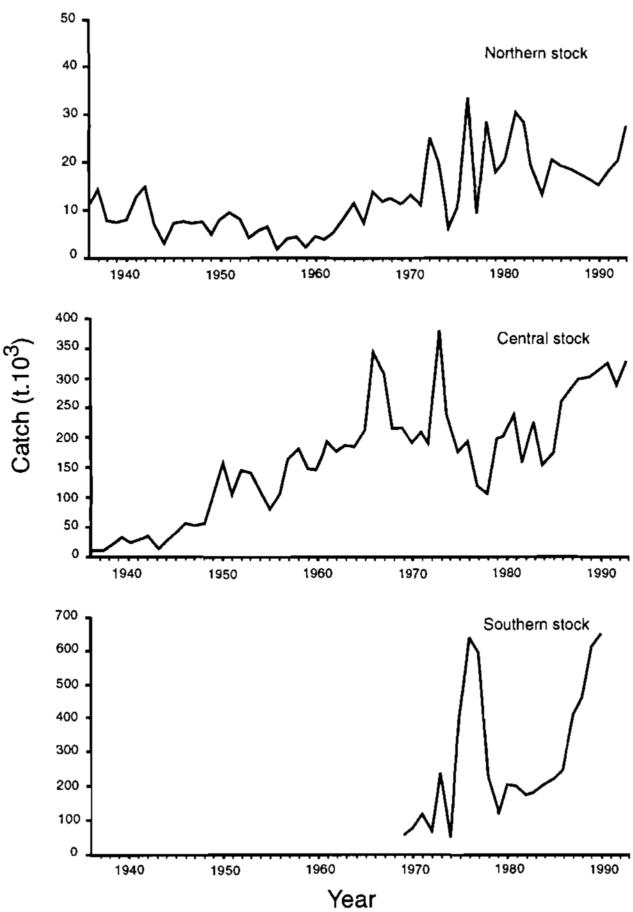


Fig. 3: Annual catch of sardine from the northern, central and southern stocks off Morocco.

1.2.3- Central stock (Cape Cantin - Cape Bojador)

Overall catches from the central stock increased gradually from the beginning of the fishery in area A to the late 1960s and then fluctuated around 250 000 tonnes (Fig. 3b). The analysis of the sardine landings in area A (Fig. 4) shows that after a period of increase lasting until 1965 and relative stability (except for two exceptionally good years 1966 and 1973), a decrease occurred. Towards the end of the 1980s and the beginning of the 1990s, catch level in the area reached the lowest observed values since the end of the 1940s. On the other hand, the Spanish catch in the B area showed a regular increase in 1976-77, then stabilized around 100 000 t per year (Fig. 5b). This stabilization coincided with the decline of the Moroccan catch in area A. This decline incited the Moroccan to extend fishing effort southward to zone B, where Moroccan landings are still increasing (Fig. 5b).

Fig.4: Sardine landings in the Moroccan traditional fishing area Central Stock, Area A from 1936 to 1993.

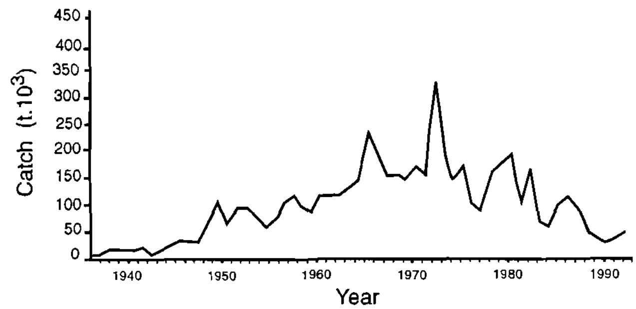
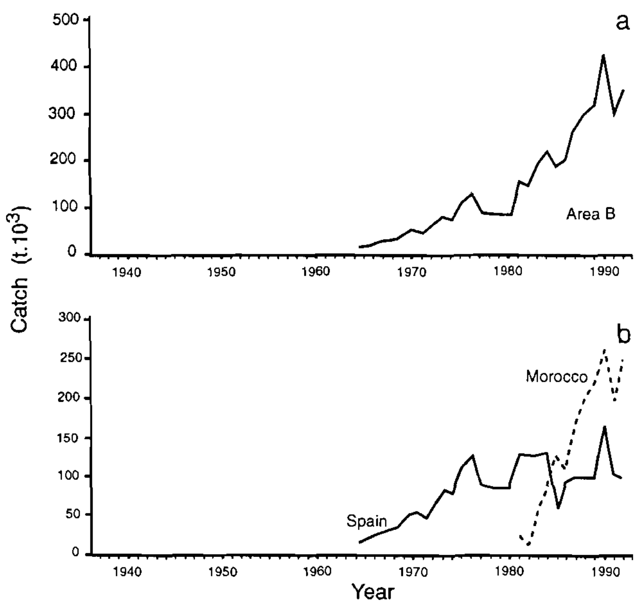


Fig. 5: Catch of sardine in fishing area B (a) total catch; (b) catch of the Spanish and Moroccan fleets.



The CECAF Ad hoc Working Group on Sardine (FAO, 1985) concluded that an important decrease of central stock abundance occured from 1971 to 1976. Abundance then increased in 1977 and then decreased again from 1986 onwards (FAO, 1990). According to the acoustic estimations of *R.V. Dr Fridtjof Nansen* carried out in December 1986, August 1989 and January-February 1992, the central sardine stock seems to have drastically decreased, from 1.5 million t in 1986 to 320 000 t in 1992. Recruitment has widely varied since the early 1970s. Average recruitment of 1968 and 1969 were followed by the relatively strong year class in 1970 which dominated in the catch until 1974. Recruitments declined afterward, except for 1978,1980 and 1982 (Fig. 6).

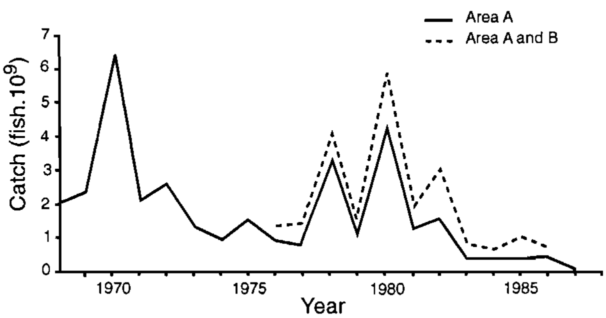


Fig. 6: Catch (0 + 1 year class) from the central stock (juveniles+recruits) (from Belvèze, 1984 and other sources).

Analysis of catch data in different ports of area A shows that the decline of sardine catch started in 1967 in the northern port of Safi then spread southward after 1973 to the ports of Essaouira and Agadir (Fig. 7). Overall, it appears that there has been a southward shift of location of the central sardine catches. In regard to the schoaling behavior of the sardine, it is likely that as its abundance declined, the central stock contracted its range towards the spawning area (Kifani and Gohin, 1992).

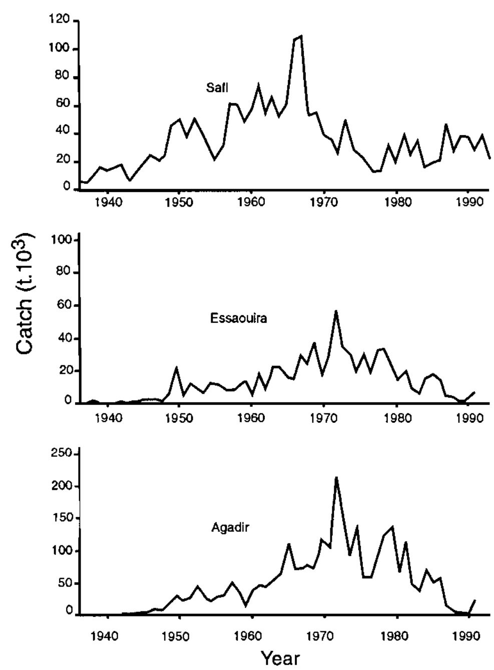


Fig. 7: Landings of sardine, central stock, area A, at Safi, Essaouira and Agadir showing southward range contraction.

1.2.4- Southern stock (Cape Bojador - Cape Blanc)

The southern boundary of the Saharan stock has widely fluctuated during the past decades. According to the surveys carried out by the Soviet Union since 1957 in northern CECAF region, southern limit of sardine along the Moroccan coast, before 1967, was approximately Cape Bojador. The Saharan stock outburst and its consecutive equatorward extent started toward 1967 and continued during the early 1970s. As sardine range expanded to the south, *Sardinella* distribution area regressed equatorward (Binet, 1988; Binet *et al.,* this vol.; Demarcq, this vol.). Some concentrations of sardine were even found off Senegal (Fréon and Stequert, 1979).

Sardine have progressively replaced the mackerel, horse mackerel and sardinellas that dominated the catch during the 1960s. Sardine catches underwent a rapid growth from 80 000 t in 1969 to 643 000 t in 1976 (Fig. 3c). Catches declined after the mid-1970s and remained at levels of 100 000 to 200 000 t till the end of 1980s. A further remarkable increase occurred in 1987, most likely consequent upon a strong year classes formed during the late 1980s.

With regard to the reverse trends presented by the central and Saharan stocks of sardine, which experienced a southward shift the question arises: what happened to sardine at the northern limits of its distribution area?

1.2.5- Sardine off European Atlantic coast

One feature of the eastern boundaries of the oceans is the extention of the temperate zone to low latitudes due to coastal upwelling and equatorward surface flow (Parrish *et al.*, 1983). As a result, the Atlantic sardine *(Sardina pilchardus*), a species of temperate region, extended between 10°C surface isotherm in the north and 20°C surface isotherm in the south (Fig. 8). The northern end its range overlaps with that of the distribution of herring; while its southern end overlaps with the distribution of sardinellas (Robles *et al.*, 1992).

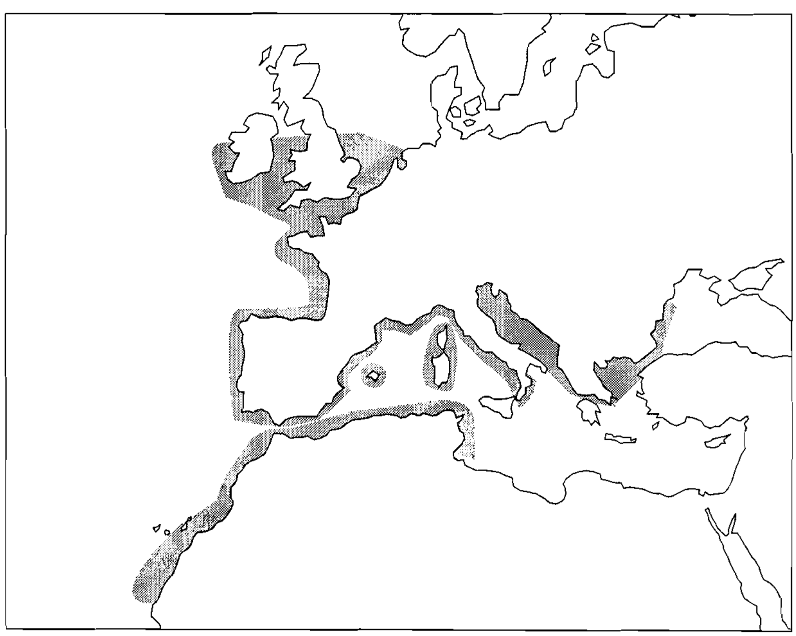


Fig. 8: Geographical distribution of *Sardina pilchardus* (from Belvèze, 1984).

Atlantic sardine form several stocks along the European and Northwest African coasts. The Atlantic sardine off Europe comprises two stocks: the Bay of Biscay / North Sea stock and the Iberian stock (from the Gibraltar Strait to the Cantabrian coast).

According to Cushing (1982), Southward and Boalch (1988) and Dickson *et al.* (1988) the sardine had also undergone some changes along the West European coast (Fig. 9). The Iberian sardine catch declined since the mid-1960s to the end of the 1970s, then increased again in the early 1980s. In the Eastern North Atlantic region, where long-term ecosystem variations are well documented, a sequence of modifications was noted from 1925-1935 onwards which was accompanied by a long-term fluctuations of *Sardina pilchardus* abundance in the English Channel (Southward and Boalch, 1988). From 1936 onwards, sardine eggs became abundant and this species replaced herring *Clupea harengus* as the dominant pelagic fish. Between 1965 and 1975, sardine spawning underwent a reduction in intensity and towards 1968 *Scomber scombrus* had begun to replace *Sardina pilchardus* as the dominant species till 1984 where sardine spawning peaked.

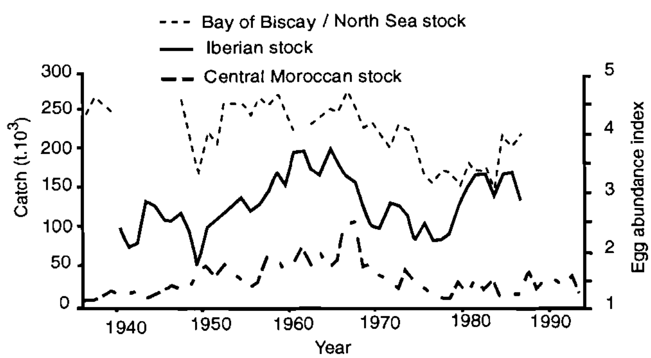


Fig. 9: Indices of *Sardina pilchardus* abundance in the English Channel (eggs survey data from Southward and Boalch, 1988) and catches off the Iberian Peninsula (P. Cury, pers. comm.) as compared with landings of sardine at Safi, Morocco.

We can note that while the sardine was expanding its range to the south in the late 1960s and early 1970s, its abundance was decreasing in the English Channel, Portugal and, simultaneously, on Moroccan fishing area A. If we take into account the broad distribution of *Sardina pilchardus* and the heterogeneity of its stocks and fishing areas, one could suspected a large scale climatic effect to have triggered sardine abundance and distribution changes. The outburst of *Sardina pilchardus* may be related to the strengthening of the upwelling off Sahara in the early 1970s (Sedykh, 1978; Domanevsky and Barkova, 1981; Belvèze and Erzini, 1983), while the intensification of the upwelling off Portugal during the same period has adversely affected the Iberian sardine (Dickson *et al.*, 1988).

2. Environmental changes

The principal hydrographic feature of the Moroccan Atlantic shelf is the upwelling of cold waters and its associated offshore Ekman transport, both driven by the trade winds (Wooster *et al.*, 1976; Parrish *et al.*, 1983). The general surface flow in this region is linked to the Canary Current.

Wind speed, offshore Ekman transport and sea surface temperature changes from 1946 to 1990 in three areas off the west coast of Morocco are presented in Figure 10. These data were provided by the National Center for Atmospheric Research (U.S.A) and extracted from the COADS file (Comprehensive Atmospheric Data Set, Roy and Mendelssohn, this vol.). Each of the three variables presents a similar trend. Wind speed and offshore Ekman transport intensity shows a sustained upward trend since the early 1950s which reversed toward the mid-1970s. At the same time sea surface temperature decreased progressively, then increased in the mid-1970s.

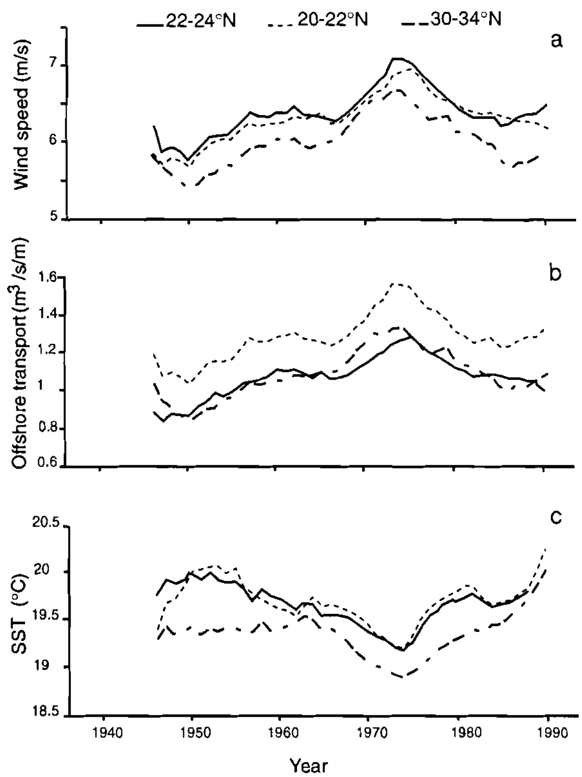


Fig. 10: Smoothed time series of (a) wind speed (m/s), (b) offshore Ekman transport ($m^3/s/m$) and (c) sea surface temperature (°C). (Data from COADS).

On the other hand, long-term observations of the air temperature at two Atlantic coastal stations, Casablanca and Essaouira, provided by the National Meteorology Office have shown a tendency towards cooling from the early 1960s, which became stronger during the 1970s, and then reversed itself towards the end of this decade (Fig. 11a,b). These observations are in accordance with those made by Le Goff (1985) on the evolution of the temperature in Morocco and are also in agreement with the temperature change in the whole North Atlantic region described by Cushing (1982) and Kelly (1983, 1984).

Lamb and Peppler (1987) have stressed the influence of the two main North Atlantic atmospheric centers (Azores High and Iceland Low) on the Moroccan climate. The variations of these atmospheric centers are also involved in large scale climatic changes in the North East Atlantic region (Kelly, 1984). Although the mechanisms involved are far from clear, it is likely that the long-term climatic evolution in Morocco is broadly linked to the large-scale climatic change in the North Atlantic region. As suggested by Dickson *et al.* (1988), the strengthening of northerly wind activity during the 1960s and 1970s have most probably affected all the West European and Northwest African coasts and resulted in an increase in coastal upwelling activity.

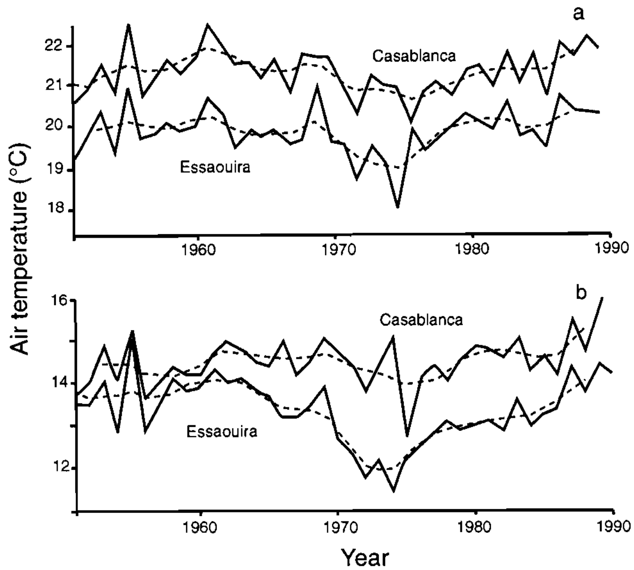


Fig. 11: Long-term changes of air temperature at two coastal stations: Casablanca and Essaouira, Morocco, (a) maxima; (b) minima.

3. Discussion

Several long-term trends appear to be simultaneous in sardine abundance data and the environmental record. The widespread southward movement of sardine appears to be associated with the 1960s and 1970s strengthening of northerly winds. The question rises why do the same climatic factors affect the various stock differently?

According to Cushing (1982) the most probable way in which large scale climatic changes may influence fish stocks abundance over wide areas may be through primary and secondary production. Changes in these factors would result in marked differences in recruitment. From studies of phytoplankton blooms, it is evident that phytoplankton responds to changes in the intensity of wind (stress and mixing), which is associated with vertical stratification and determines the availability of nutrients in the upper layers of sea water (Radach, 1984).

In temperate regions, the production cycle may vary in amplitude, spread and time of the onset owing to differences in wind strength and direction (Cushing, 1982). Large scale effect of climate on phytoplankton and zooplankton biomass in the Eastern North Atlantic region have been studied by Dickson *et al.* (1988). Long-term increase in the northerly wind component over the Eastern North Atlantic and the North Sea between the 1950s and the 1970s was associated with a decline in phytoplankton and zooplankton biomass. Dickson *et al.* (1988) assume that the strengthening of the wind has induced a reduction and delayed the spring phytoplankton outburst and hence lead to a reduction of suitable food for zooplankton.

Strong winds off Moroccan coast generates a strong offshore advection and turbulence that alters phytoplankton production and induce a time-space lag between the phytoplankton and zooplankton. With an increase wind stress, the higher zooplankton biomass are advected to the shelf edge where the zooplankton makes good use of the phytoplankton that develops in the upwelled water drift (Binet, 1988, 1991). Strong upwelling favors large diatoms colony (e.g., *Thalassiosira parthenia*) that are not grazed by zooplankton (e.g., copepods). In contrast zooplankton species can feed very effectively on short food chains or single cells in older upwelled waters, where colonies disintegrate due to senescence (Elbrächter, 1982; Schnack, 1983).

The three areas of sardine production in Morocco are all characterized by a source of upwelling water and spawning ground which correspond to a region with wide continental shelf. Spawning seasons for the three stocks are out of phase with that of the upwelling maximum (Belvèze, 1984; Barkova and Domanevsky, 1985). From this point of view, the Moroccan sardine populations present the same reproduction pattern, the one difference being in the latitudinal position of the spawning grounds. The northern and the central population spawning grounds (respectively off Casablanca-Larache and off Sidi Ifni-Cape Juby) are downstream of the summer upwelling maxima, which occur between Larache and Tanger in the northern area and between Cape Sim and Cape Ghir. On the contrary, the Saharan spawning area overlaps with the Cape Bojador-Cape Garnett zone (Belvèze, 1984). This would suggest that the southern stock is more adapted to strong upwelling conditions. Inspecting somatic index of *Sardina pilchardus* from fifteen geographical areas, Andreu (1969) concluded that the sardine population with a high number of gill-rakers lives in areas with fluctuating environment. On the other hand, Furnestin (1950) and Furnestin and Furnestin (1970) found that the number of gill-rakers increase from the north to the south. This feature would allow the southern sardine to feed more efficiently on phytoplankton. Nieland (1980) found that the principal food item of sardine off Sahara was phytoplankton while in the central area, sardine fed mainly on zooplankton. Permanent upwelling and high primary production would explain this difference in diet, which results in a difference in growth rate that are in the southern area (Domanevsky and Barkova, 1981; Belvèze, 1984). Domanevsky and Barkova (1981) showed that the growth rates of southern sardine increase with upwelling intensity.

Having a phytoplanktivorous diet, and greater growth rates, the southern population may have been favoured by the strengthening of northerly winds along the European, and Northwest African Atlantic seaboards during the 1960s and the early 1970s, which have seemingly led to a rejuvenation of the ecosystems (Binet, 1988). Southward and Boalch (1988) found a good correlation between *Calanus* and *Sardina* egg numbers and they assumed that spawning depended on availability of copepods food. Referring to the CPR survey (Dickson *et al.*, 1992) noted a downward trend of copepods abundance between the 1950s and 1970s in the North East Atlantic region. Off Portugal, Dickson *et al.* (1988) offered an explanation for the inverse relationship between sardine and upwelling intensity: the fact that weak upwelling favors the development of a suitable initial food supply for the larvae and nauplii, which feed on small algae cells, and are thus better able to develop during weak upwelling episodes.

4. Implications for the Moroccan sardine fishery

The reduction in the distribution range of the central stock of sardine, traditionally exploited by the Moroccan fishery, added to various political and economic factors, had a serious impact on the Moroccan fishing industry. Until the beginning of the 1980s, processing plants were located in the traditional fishing area (from Safi to Agadir) where the fishery activity was able to provide sufficient raw materiel. To help this industry to survive, Morocco expanded the exploitation in the 1980s to the southern area which harbors the bulk of the central stock. Hence processing plants were opened in the southern ports. If the fishery is now less subject to productivity constraints, it still remains under strong profitability constraints. The gain produced by increasing the catch in order to supply factories (mainly fish meal factories) is wasted, because of the increase of fishing costs. Under such conditions, the profitability of the Moroccan sardine fishery depend largely on the abundance of the central stock. Considering the alarming level attained by fishing mortality, this stock may place the fishery and downstream activities in a difficult position.

Thus, if the strategy presently adopted by Morocco for the management of the sardine stocks and fishery is to continue (namely a search for a profitability by increasing catches), the long-term perspective of the Moroccan sardine fishery should be to exploit the Southern stock. More studies are needed to establish a viable strategy for the exploitation of the southern stock by Moroccan fishers. In this respect, understanding the spatial and temporal dynamic of the sardine stocks and their links with climatic fluctuations is of paramount importance.

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