Changes in the Dynamics and Biology of small Pelagic Fisheries off Côte-d'Ivoire and Ghana: an Ecological Puzzle

OLIVIER PEZENNEC*

KWAME A. KORANTENG**

* Centre National des Sciences
Halieutiques de Boussoura
(ORSTOM/CNSHB)
BP 1984
Conakry
GUINEA

**Fisheries Research & Utilization Branch
(FRUB)
P.O. Box B-62
Tema
GHANA

ABSTRACT

Spatio-temporal changes in the dynamics of small pelagic fisheries in the Ghanaian-Ivoirian coastal marine ecosystem and changes in the biology of the fish are examined. The abundance of the *Sardinella aurita* population appears to show a transition from a depleted to a prosperous state over the last two decades. These drastic changes is puzzling as it does not appear to be in conformity with previous knowledge on the fish and fisheries of the western Gulf of Guinea ecosystem. The strengthening of minor upwelling appears to be the most likely cause for these observed changes.

RÉSUMÉ

Les dynamiques spatiales et temporelles des petits pélagiques côtiers de l'écosystème ivoiro-ghanéen et les changements dans la biologie des poissons sont examinés. Durant les deux dernières décennies l'abondance de la population de *Sardinella aurita* est passée d'un état en déplétion à un état prospère. Ces changements drastiques n'apparaissent pas en conformité avec les précédentes connaissances acquises sur les espèces et les pêcheries de l'ouest du Golfe de Guinée. Cependant, le renforcement du petit upwelling apparaît comme la seule cause probable responsable des changements observés.

INTRODUCTION

Coastal pelagic fisheries in the western Gulf of Guinea (between Côte-d'Ivoire and Benin) exploit several fish stocks. Between 1983 and 1990, total annual landings were estimated at $200\text{-}260.10^3$ t in the whole sub-region (FAO, 1992). Four species are particularly important, namely: anchovy *Engraulis encrasicolus* (Linnaeus, 1758), chub mackerel *Scomber japonicus* (Houttuyn, 1782), round sardinella *Sardinella aurita* (Valenciennes, 1847) and flat sardinella *S. maderensis* (Lowe, 1839; Whitehead, 1967). Annual landings of *E. encrasicolus* and *S. aurita* attain 100.10^3 t but the landings of *S. japonicus* and *S. maderensis* are much smaller. A third sardinella species *S. rouxi* (Poll, 1953), is also fished in the region. However, because of its small size (generally less than 15 cm), the species is confused with juvenile *S. maderensis* and is not separated in the statistics except in Ghana (Mensah and Koranteng, 1988). Since the 1980s, there has been a substantial increase in the landings of *S. aurita*. Changes in the distribution and abundance of the species have also been noticed (Pezennec and Bard, 1992). This evolution of the fishery contradicts most of the knowledge acquired in the 1960s and 1970s about this resource. The abundance of the other species of this pelagic ecosystem have also fluctuated, but not as much as *S. aurita*. Significant changes in some aspects of the biology of *S. aurita* have also been observed. Size of fish caught and size at first maturity have increased and spawning activity outside the known main spawning season has intensified.

These and other recorded changes in the biology and dynamics of *S. aurita* in the western Gulf of Guinea ecosystem in the last two and a half decades, constitute what may be described as the 'Sardinella puzzle'. This paper presents some pieces of the puzzle and discusses the merits and demerits of hypotheses that have been put forward to explain the observed changes.

1. AVAILABLE DATA AND ANALYSIS

The data used in this paper were obtained from the landings of purse-seiners and canoes in Côte-d'Ivoire and Ghana. They are as follows:

- Total annual catch of the Ghanaian and Ivoirian sardinella fishing crafts from 1966 to 1993;
- Fortnightly catch, effort (in days of search), catch per unit of effort (CPUE) for the Ivoirian purse seiners in seven fishing areas (delimited by degrees of longitude) off Côte-d'Ivoire and Ghana for the same time period;
- Annual catch, effort (in trips) and CPUE in Ghana from 1972 to 1993 and for four fishing area (administrative areas from West to East: Western, Central, Greater Accra and Volta Region);

- Selected length-frequency data on sardinellas in Ghana and Côte-d'Ivoire, since 1963 and 1968, respectively;
- Maturity stage, gonad weight and body weight of female fishes obtained from two periods: 1964-1970 (in both countries) and 1988-1991 (in Côte-d'Ivoire).

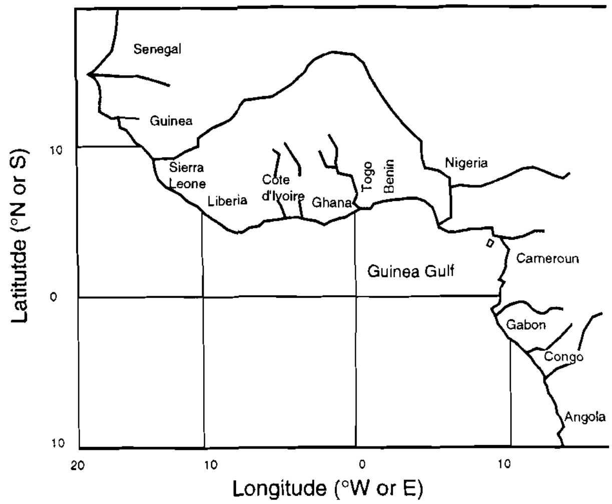


Fig. 1a: West Africa from Senegal to Angola (from Binet, 1983).

To fish for Sardinella, the canoes use a gillnet called 'Ali', and beach seines and purse seine-type nets called 'Poli' and 'Watsa' in both Ghana and Côte-d'Ivoire. However, these three gears are lumped for statistical purposes and in this paper their catch, effort and CPUE are labeled as APW in the figures.

In spite of its limitation for assessment of pelagic fish stocks, CPUE is used here as the index of abundance. As pelagic fish are usually found in schools, their abundance has two components: the size of the school and the number of schools per unit area (spatial density).

The gonado-somatic index GSI, defined as GW/aL^n where GW is the gonad weight, L is the fork length of the fish, and n is the exponent in the length-weight relationship, was used to describe spawning activity. Following Ni and Sandeman (1984), length at first maturity (L_m) was estimated from a logistic relationship of the form:

$$P = 1/(1+e^{-(a+bL)})$$

where P is the estimated proportion of mature fish at fork length L, and a and b are constants. The logit of the equation, i.e.

$$\text{Logit } P = \text{Ln}(P/(1-P)) = a + bL$$

gives the length at first maturity, L_m, for $P = 0.5$.

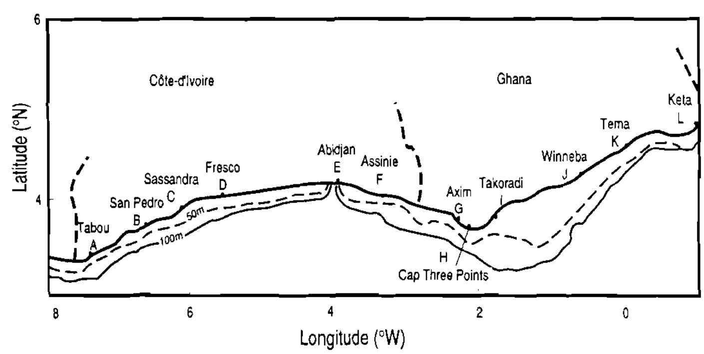


Fig. 1b: Ivoirian and Ghanaian continental shelves and coastal stations.

2. Observed changes

2.1. Catch, abundance and dynamics

2.1.1- Evolution of fishing effort

The activity of the small-scale fishing fleets (canoes and beach seines) increased in both countries from the mid 1970s to the mid 1980s (Fig. 2). From 1983 to 1989, the number of fishing trips by canoes fishing for small pelagics in Ghana first declined, then increased. In Côte-d'Ivoire, the effort of the Ivoirian purse-seiners decreased between 1969 and 1975; there was a fifty percent reduction in the number of boats in 1973. Effort began to rise in 1976, reaching a maximum in 1979 and then declined again afterwards. There has been a steady growth in the effort of this fleet since 1985.

2.1.2- Trends in the landings and abundance of S. aurita

Until 1972, total landings of the two sardinella species in the whole of the western Gulf of Guinea never exceeded 50.10^3 t. During the 1972 fishing season, over 70.10^3 t of *S. aurita* was caught off Ghana alone, leading to an apparent "overfishing". Between 1973 and 1975, catches dropped to an average of 4 400 t from the whole sub-region. In 1976, a recovery was noticed with the Ghanaian catch alone reaching about 14 000 t (Fig. 3). In subsequent years, catches fluctuated with an underlying increasing trend. During the same period, catches off Côte-d'Ivoire increased

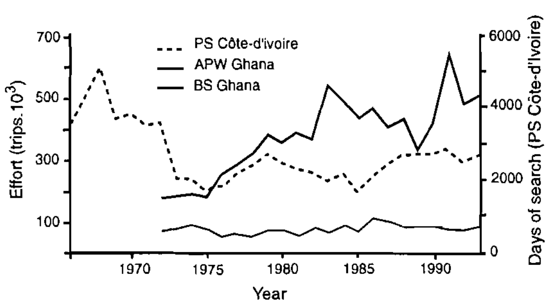


Fig. 2: Annual effort of the Ghanaian beach seine (BS) and Ali-Poli-Watsa nets (APW) and of Ivoirian purse seiners (PS), 1972 (or 1966) to 1993.

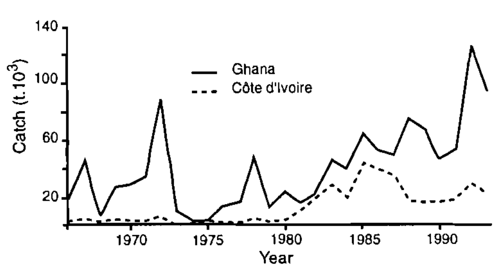


Fig. 3: Annual catch of *S. aurita* off Côte-d'Ivoire and Ghana, 1966 to 1993.

ten fold. Since 1983 high catch and abundance have been observed in both countries, and catches recorded after 1985 have either been similar to, or exceeded those of 1972. The highest total catch, in excess of 154.10^3 t, was in 1992.

2.1.3- Catch of the other small pelagic fish species

Landings of *S. maderensis* remained relatively stable from 1972 to 1992 (20 - 40.10^3 t per year) in the whole sub-region, except in 1987 when 48 200 t were landed (Fig. 4). There was also a steady increase in the landings of anchovy (*Engraulis encrasicolus*) during the last two decades, with relatively low landings in some years (1973, 1986). Over 90.10^3 t were caught in both countries in 1987. Large fluctuations in the landings of chub mackerel (*Scomber japonicus*) were observed. The combined effect is a global increase of catches of coastal pelagic species of this ecosystem in the period for which data are available.

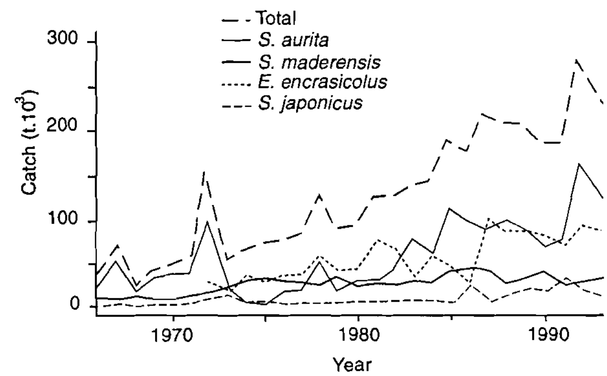


Fig. 4: Total annual landings of major small pelagic species in Ghana and Côte-d'Ivoire (*Sardinella aurita, S. maderensis, Engraulis encrasicolus, Scomber japonicus*).

2.1.4- Variation of catch and abundance with fishing effort

For *S. aurita*, the trend of catch per unit effort (CPUE) of APW canoes or beach seines in Ghana and for purse seiners and APW canoes in Côte-d'Ivoire are presented on Figure 5. Catch and CPUE of *S. aurita* are distributed in accordance with the state of the resource (Fig. 6): for the Ivoirian seiners, the inter-annual variability of total catch or CPUE with effort is very important, especially in view of the lower level of effort. Before 1981, catch and CPUE were low and increased with fishing effort. After 1981 catch and CPUE, which were much higher than in previous years, decreased with effort. The analysis of the Ghanaian data showed that in the case of *S. aurita* a situation is quite similar to that in Côte-d'Ivoire. Here, in the period 1973-1980, there were generally low values of CPUE with increasing fishing effort. With the exception of 1986, high values of CPUE have been recorded since 1985. For *S. maderensis*, in Côte-d'Ivoire, the years are randomly distributed and both catch and CPUE are highly variable given an average level of effort (Pezennec, 1994). Similar analysis of the Ghanaian data for this species showed that catch and CPUE decreased with increasing canoe effort.

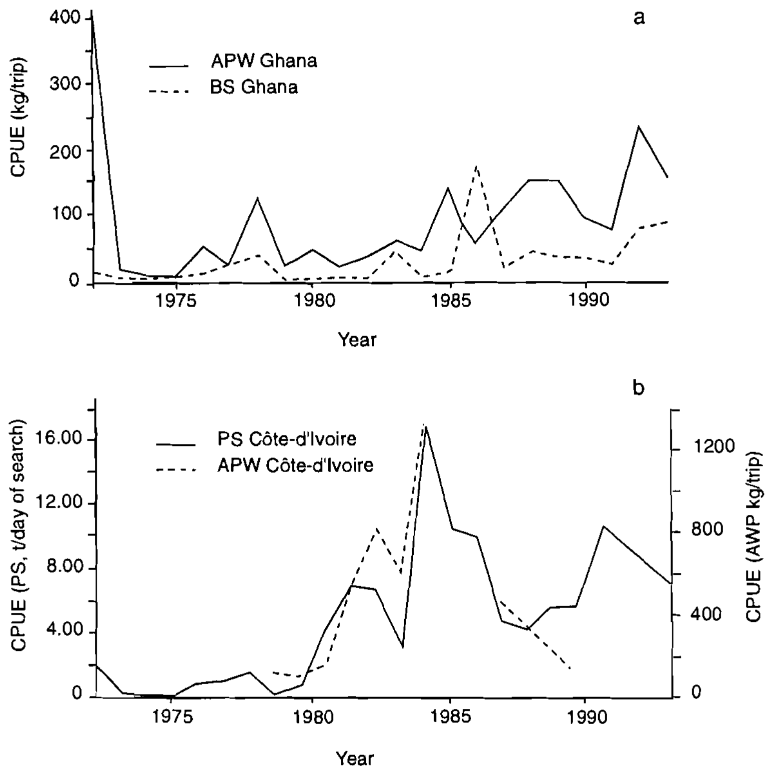


Fig. 5: Catch per unit of effort (CPUE) of *Sardinella aurita* for (a) the Ghanaian and (b) Ivoirian fleets, 1972 to 1993.

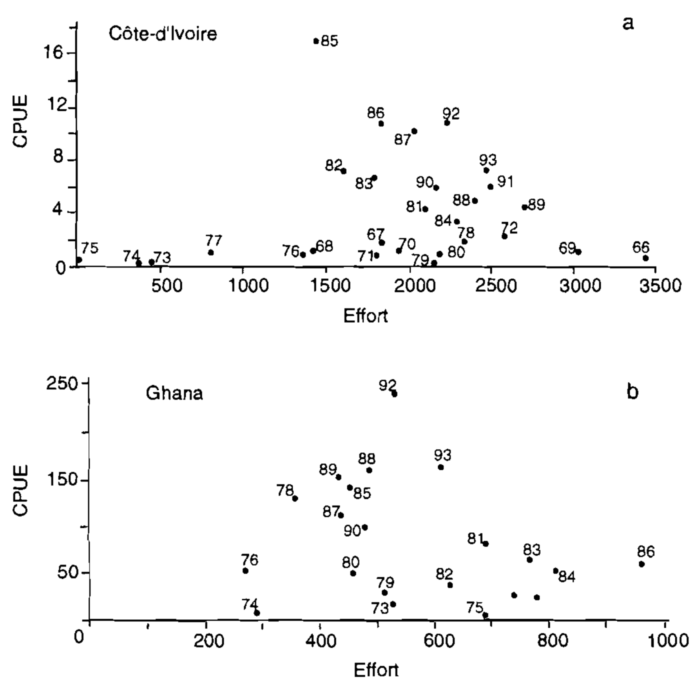


Fig. 6: Annual abundance (catch per unit of effort) of the *Sardinella aurita* off (a) Côte-d'Ivoire and (b) Ghana and theoretical effort (catch/CPUE).
Côte-d'Ivoire: CPUE: tonnes per day of search; effort: days of search.
Ghana: CPUE: kg per trip; effort: thousands of trips. For Ghana the year 1972 is not represented (CPUE= 400).

2.1.5- *Development of* S. aurita *abundance in Côte-d'Ivoire and changes in the species composition of catch*

In Côte-d'Ivoire, the average abundance (CPUE) of *S. aurita* observed during the eighties was ten times higher than during the previous years (Fig. 7). Indeed, this species became more important than *S. maderensis* and *Brachydeuterus auritus* (Pezennec, 1994), which had dominated the catch of small pelagics in the 1960s and 1970s in this country.

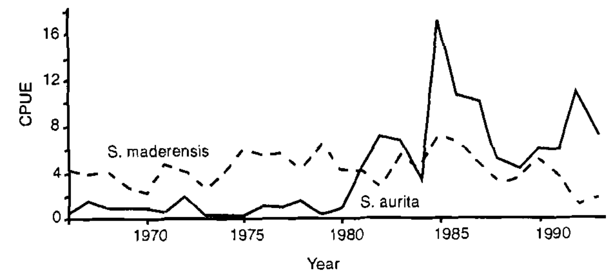


Fig. 7: Annual abundance (CPUE) of *Sardinella aurita* and *S. maderensis* off Côte-d'Ivoire from 1966 to 1993 (t per day of search for the purse seiners).

2.1.6- *Extension of the spatial distribution of* S. aurita

The increase of the abundance of *S. aurita* off Côte-d'Ivoire was accompanied by a spectacular extension of its distribution to the western part of the country. Since 1980, the CPUE of purse seine operations in western Côte-d'Ivoire have exceeded those from the east except for four years (Fig. 8). A similar increase was seen in the western part of Ghana where, although landings in the western areas always exceeded those from the east, the difference has widened since 1987. There were no similar changes in the distribution of the other small pelagic species in either country.

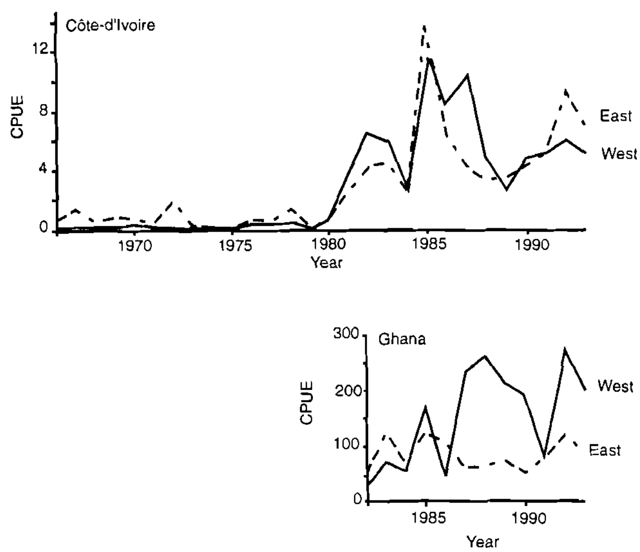
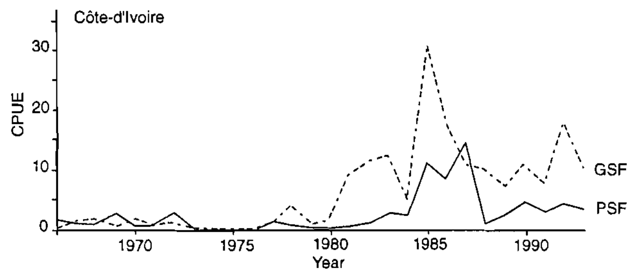


Fig. 8: Abundance of *Sardinella aurita* off the western and eastern parts of Côte-d'Ivoire (1966-1993) and of Ghana (1982-1993). Côte-d'Ivoire: t per day of search for purse seiners. Ghana: kg per trip for APW nets.

2.1.7- Importance of the S. aurita *abundance during the minor upwelling season*

Figure 9 presents CPUE values recorded during two periods, the major upwelling season and the minor upwelling season in Côte-d'Ivoire and Ghana. Whereas, in Ghana, CPUE values in the major upwelling are always higher than those in the minor upwelling, the situation is different in Côte-d'Ivoire. In the latter country, CPUE values for the GSF and PSF were equally important. Values in the GSF increased dramatically in 1981 and in subsequent years. The PSF has assumed greater importance since 1983-84, and in 1987, the CPUE recorded during this season exceeded that of the GSF. Also in Côte-d'Ivoire, there is a difference between the western and eastern parts of the country. In western Côte-d'Ivoire, the minor upwelling is as important as the major upwelling for the sustainability of the species (Pezennec, 1994).



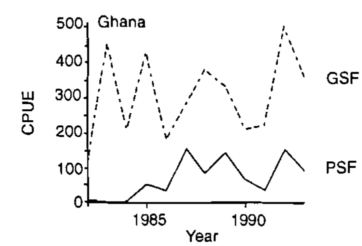


Fig. 9: Annual abundance (CPUE) of *Sardinella aurita* during the minor (PSF) and major (GSF) upwelling seasons off Côte-d'Ivoire (1966-1993) and off Ghana (1982-1993). Côte-d'Ivoire: t per day of search for purse seiners. Ghana: kg per trip for APW nets.

In all these, the limitation on the use of CPUE in pelagic resource assessment, as discussed in many studies (e.g., Saville, 1980) need not to be overlooked. One such limitation is that of the spatial distribution of the stock and (or) the fleet is reduced, the CPUE could remain constant (or even increase) even though the biomass have decreased. In this case, the abundance of *S. aurita* has increased as well as his spatial distribution.

2.2. Biological changes

2.2.1- Increase in sizes of fish caught

In the early 1960s and 1970s, the modal size (fork, length) of *S. aurita* caught off Côte-d'Ivoire was between 15 and 18 cm (ORSTOM/FRU, 1976; Fig. 10). During the 1980s, this modal size was between 18 and 24 cm and a similar increase of the maximum size of the fishes caught was also observed. In Ghana, an increase of the modal size was also observed, from 14-17 in the early 1960s to 17-21 in the 1980s.

Also observed is an increase in the length at first maturity of *S. aurita* in Côte-d'Ivoire from 15-16 cm in 1969 to 19-20 cm in 1990 (Fig. 11). Quaatey (1993) similarly noted an increase for female fish caught in Ghanaian waters, from 14.5 cm to 17.1 cm.

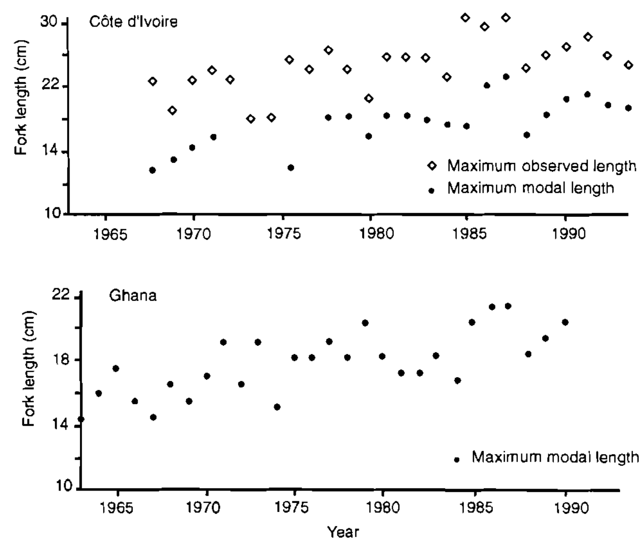


Fig. 10: Maximum modal length and maximum observed length (fork length, in cm) of *Sardinella aurita* caught off Côte-d'Ivoire and Ghana from 1963 to 1990.

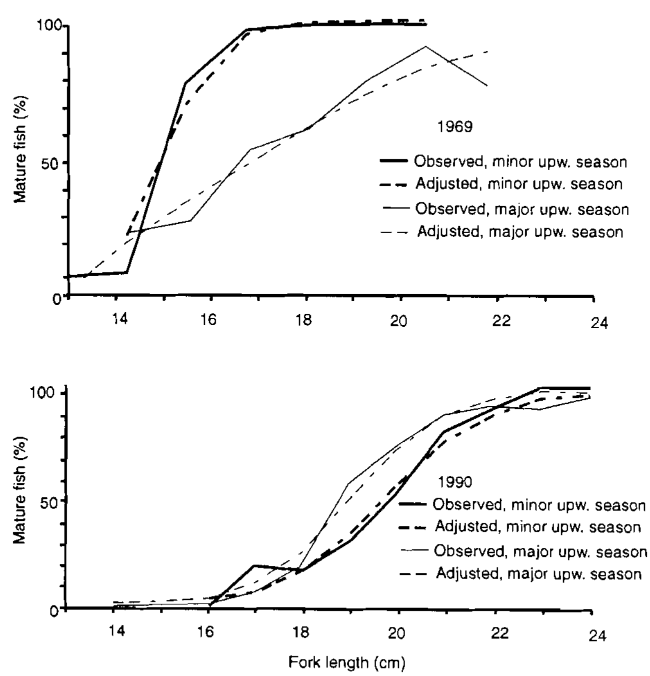


Fig. 11: Sexual maturity of the females of *Sardinella aurita* caught off Côte-d'Ivoire during the 1969 and 1990 upwelling seasons: percentage of mature fishes observed and adjusted values (logistic function).

2.2.2- *Changes in spawning activity*

S. aurita was known to spawn mainly during the upwelling seasons (ORSTOM/FRU, 1976), especially during the major upwelling. In Côte-d'Ivoire, observed GSI were during the minor upwelling season and part of the warm season (March, April), as large as during the major upwelling season (Fig. 12). In recent years, it has become clear that both cold periods occurring off Côte-d'Ivoire are fully utilized by *S. aurita* for spawning. Quaatey (1993) also reported an increased gonadal development and spawning activity of the *S. aurita* outside the major upwelling season. No such changes were observed for *S. maderensis* (Pezennec, 1994).

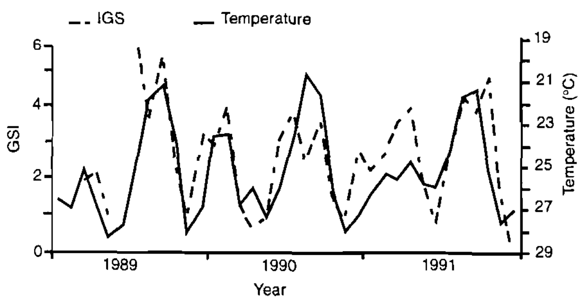


Fig. 12: Gonado-somatic index of *Sardinella aurita* caught off Côte-d'Ivoire and mean temperature (from warmer to colder) off Tabou and Abidjan. Monthly means, 1989-1991.

2.3. Influence of the biological changes on the dynamics of fish and fishery

The general increase in size of fish has effect on the total weight of fish landed. In Côte-d'Ivoire, for example, similar numbers of *S. aurita* individuals were caught during the 1986 (120 millions) and 1988 (140 millions) fishing seasons, but the landed weight in 1986 was double that of 1988 (Pezennec, 1994).

All things being equal, the increase in size at first maturity and modal size should result in increase in the fecundity of the fish. A fish of 23 cm long is expected to release a quantity of eggs twice as high as a 18 cm long fish (Fontana and Pianet, 1973; Boëly, 1982). This increase in fecundity may result in an increase of recruitment and hence, of the total biomass of the fish.

3. Discussion

3.1. Hypotheses

The observed changes in the dynamics and biology of *S. aurita* surely constitute a puzzle, the solution of which possibly requires a deeper understanding of the fishery and the nature of changes in the physico-chemical parameters of the

Ivoiro-Ghanaian ecosystem. Some of these changes in the past led to certain hypotheses being proposed by researchers. These hypotheses were based on observations of the fluctuations in the biotic and abiotic components of the ecosystem.

One of the earliest suggestions attributed the decline of *S. aurita*, in part, to the increase of triggerfish *Balistes capriscus*, a semi-pelagic fish in coastal waters off Côte-d'Ivoire, and especially off Ghana (ORSTOM/FRU, 1976). *B. capriscus* drastically declined since 1988 (FAO, 1992). It is obvious now that, although the rise and fall of *B. capriscus* was observed between 1970 and 1988, and the decline of *S. aurita* occurred during the early part of this period, the recovery of the round sardinella began before the decline of the triggerfish. Furthermore, except perhaps for their juveniles, the two species do not have the same ecological requirements (Caverivière, 1991).

Various models developed to facilitate understanding of the dynamics of the pelagic resources of Côte-d'Ivoire and Ghana (Binet, 1982; Cury and Roy, 1987) failed to explain the increase in abundance of *S. aurita* in the 1980s (Pezennec, 1994).

Increase in wind speed has been suggested to lead to an increase of upwelling off Côte-d'Ivoire and Ghana (Roy, 1992). However, these upwellings are not entirely related to the wind and in fact, the annual values of mean temperature and wind speed or Ekman transport.are positively correlated during the GSF and showed no relationship during the PSF (Pezennec and Bard, 1992). Thus, increase of wind speed has not led to an increase of upwelling. However, an increase in this environmental factor leads to increase of superficial mixing and turbulence, which have been hypothesized to increase productivity only if wind speed does not exceed 6 $m.s^{-1}$ (Cury and Roy, 1989).

Binet *et al.*, (1991) and Herbland and Marchal (1991) have attributed the increase of abundance of *S. aurita* off Côte-d'Ivoire to changes in water currents and (or) intensity of the upwelling in the western and eastern regions off this country. The 'current hypothesis' is based on the notion that an increase of the westward circulation may have increased the drift of *S. aurita* larvae from the Ghanaian shelf and their retention off Côte-d'Ivoire, resulting in increased recruitment off the latter country. This hypothesis thus implies displacement of the Ghanaian stock of *S. aurita* towards Côte-d'Ivoire and a decrease of recruitment of the species off Ghana. Following this hypothesis, a decline in abundance of *S. aurita* should occur off Ghana. However, catches and abundance off Ghana have increased just as in Côte-d'Ivoire. Another hypothesis postulated a displacement of the centre of the upwelling off Côte-d'Ivoire from west to east. This, however, is based on a short time series of coastal sea surface temperature and obviously contradicts the observed increase in catch and abundance of *S. aurita* in the western part of Côte-d'Ivoire.

The above hypotheses have failed to explain the dynamic changes in the Ivoiro-Ghanaian ecosystem and in the biology of sardinella, particularly on its Ghanaian side. These changes constitute a puzzle of observed facts which need to be explained by a hypothesis that would take into consideration the dynamics of the fishery and of the ecosystem, and the biology of the species.

3.2. Ecological importance of the minor upwelling season

A new hypothesis, which deals with the part played by the second or minor upwelling season in the changes observed in the Ivoiro-Ghanaian coastal pelagic ecosystem was proposed by Pezennec and Bard (1992). This ecosystem is characterized by two independent upwellings. However, the influence of the minor upwelling has never been taken into consideration as an important event for the productivity of the ecosystem and for the dynamics of the pelagic species. This hypothesis gives greater importance to the minor upwelling in the sustenance of the Ivoiro-Ghanaian pelagic ecosystem, and the role that it plays regarding the biology of the *Sardinella aurita* and dynamics of the small pelagic fisheries. The hypothesis in question assumes that the intensity of the minor upwelling may have been underestimated and that the difference between the intensities of the two upwellings exhibited a decreasing trend between 1970 and 1990, as shown by Pezennec and Bard (1992) and Koranteng and Pezennec (this vol.).

3.2.1- Favourable and unfavourable periods

Outside of the major upwelling season, the pelagic species of the ecosystem studied here are faced with unfavourable condition. Several ecological theories insist on the necessity of a global approach to the population-environment system (Barbault, 1981). Taking qualitative approach to the problem of food limitation, one notes that it may be seen as sufficient on a global (annual) basis, but insufficient during a critical period or season. In this case, production of food during this period will be a limiting factor.

3.2.2- The minor upwelling season and productivity of the pelagic ecosystem

Studies into the productivity of the upwelling ecosystem have shown the importance of cooling periods outside the main upwelling season. Zooplanctonic biomass is highly correlated with these coolings (Binet, 1983). The minor upwelling season and the other cooling events occuring outside the main upwelling season are low productivity periods for the pelagic ecosystem, and may function as a 'bottlenecks' in term of productivity. So, an increase of the strength of the minor upwelling season in the ecosystem should be of great importance.

3.2.3- Importance of the minor upwelling season for S. aurita

It has been shown that the spawning activity of *S. aurita* is similar during the minor and major upwelling seasons. This provides *S. aurita* with extended opportunities for exploitation of the ecosystem in terms of spawning and recruitment. The Guinea Current creates on the eastern side of Cape Palmas and Cape Three Points two areas of cyclonic circulation which favours larval retention (Marchal and Picaut, 1977). Thus, the western part of the Ivoirian continental shelf (where the minor upwelling season is most intense) is a favourable area for larval survival.

The parallel changes of maximum length and length at first maturity are in conformity with the usual relationship between these two lengths (Beverton and Holt, 1959). According to Pauly (1984), the increase of these sizes should correspond to changes in key environmental factors (decrease of temperature or increase of the availability or density of food) which limit the growth of fish in an ecosystem.

Further, the increase of the abundance of *S. aurita* in Côte-d'Ivoire, first during the major upwelling season, and later during the minor upwelling season, may be explained by MacCall's theory (1990) of density-dependent geographic distribution of biomass.

3.2.4- Recovery from a depleted state

Figure 6 shows that the stock of *S. aurita* recovered from its previous depleted state (see Peterman *et al.* (1979) and Cury (1991)).

There have been significant changes in the dynamics of small pelagic fisheries in the Ivoiro-Ghanaian coastal marine ecosystem in the last two decades. After the decline of the fisheries in the early 1970s, total catches of the principal small pelagic species in this ecosystem (especially of the round sardinella, *Sardinella aurita*) increased in the 1980s and early 1990s. The stock of *S. aurita* appears to have recovered from its depleted state, especially off Côte-d'Ivoire. Also observed are changes in some aspects of the biology of *S. aurita*. These changes are not in conformity with earlier hypotheses put forward to explain the dynamics of small pelagics in the western Gulf of Guinea or other ecosystems. However, most of the observed changes in the biology and dynamics of *S. aurita* resources can be attributed to the increasing impact of the minor upwelling on the ecosystem. This minor upwelling, which is more intense off Côte-d'Ivoire than off Ghana, occurs during an environmentally unfavourable period of the year for the productivity of the pelagic ecosystem, and which acted as a 'bottleneck'.

No comparable changes have been observed in the biology and dynamics of the other small pelagic species of this ecosystem. Cury and Fontana (1988) have shown, for example, that *S. aurita* and *S. maderensis* have different demographic and adaptive strategies. According to these authors *S. aurita* is more sensitive to environmental fluctuations and could take advantage of them. Therefore, utilization of the relative changes in the intensity of the two upwelling seasons could be an illustration of this difference between the two sardinella species.

The stocks of the Indian oil sardine (*Sardinella longiceps*; Longhurst and Wooster, 1990) and sardinellas in the Benguela system (*S. aurita* and *S. maderensis*; Crawford *et al.*, 1987), have experienced similar changes in abundance to those observed in the Ivoirian and Ghanaian ecosystem. It would be very interesting and useful to do a comparative study of these ecosystems and their populations.

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