ECOLOGICAL IMPORTANCE OF THE IVORIAN AND GHANAIAN MINOR UPWELLING SEASON

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Abstract

This study deals with the part taken by the second and minor upwelling season in the changes observed in the Ivorian and Ghanaian coastal pelagic ecosystem. Since the early 1980s, the *Sardinella aurita* catch has clearly increased off Ghana and off the Côte d'Ivoire where the changes in abundance and dynamics of this species have been surprisingly more pronounced. The size of the fishes caught has increased and the reproductive activity now reaches the same level during the two upwelling seasons. The differences between the two upwelling's intensities shows a decreasing trend from 1970 to 1990. The increasing impact of the minor upwelling season in the ecosystem could explain the changes observed. This season, which is more intense off the Côte d'Ivoire than off Ghana, occurs in the unfavourable period of the year for the productivity of the pelagic ecosystem and could be considered as a «bottleneck» for this productivity.

Résumé :

Cette étude traite de la part prise par le petit upwelling mineur dans les changements observés dans l'écosystème pélagique côtier du Ghana et Côte d'Ivoire. Depuis le début des années 1980, les prises de Sardinella aurita ont nettement augmenté au large du Ghana mais aussi au large de la Côte d'Ivoire où les changements de l'abondance et de la dynamique de cette espèce ont été particulièrement marqués. La taille des poissons capturés a augmenté et l'activité reproductrice atteint la même intensité durant les deux saisons d'upwelling. On observe une tendance à l'atténuation des différences d'intensité entre les deux upwellings sur la période 1970-1990. L'effet accru de la saison d'upwelling mineur dans l'écosystème pourrait expliquer les changements observés. Cette saison d'upwelling qui est plus marquée en Côte d'Ivoire qu' au Ghana, apparait en une période de l'année défavorable à la productivité de l'écosystème pélagique côtier. Elle semble donc constituer un effet de «goulot d'étranglement» affectant cette productivité.

1. Introduction

The annual catch of the Ivorian and Ghanaian coastal pelagic fisheries has been estimated between 200 000 and 260 000 tonnes (FAO, 1992). The main species are two sardinella (*Sardinella aurita* and *S. maderensis*) and one anchovy (*Engraulis encrasicolus*). Anchovy (essentially caught off Ghana) and *S. aurita* catches are about 100 000 tonnes each. *S. maderensis* catch is of less importance.

Increase and spatio-temporal changes in the *S. aurita* abundance was observed during the 1980"s (FAO, 1989; Pezennec *et al.*, 1993). This evolution of the fishery contradicts most of the knowledge acquired in the sixties and early seventies about this resource. In addition, significant changes in some aspects of the biology of *S. aurita* were also observed. Modal size of fishes caught and size at first maturity have increased and spawning activity outside the known main season has intensified. Abundance of the other species of the pelagic ecosystem have also fluctuated but not as much as in the case of *S. aurita* and none of these changes has been observed for the second sardinella species.

All the papers relating to the small pelagic fishery of this area have shown the importance of the environment on the abundance and availability of these fishes. The reproduction, survival of larvae, the condition, abundance and availability of these species depends on certain condition, the most important of which are the upwellings which determine the food availability of the ecosystem (Anonymous, 1976; Cury and Roy, 1987; Mendelssohn and Cury, 1987). The main factors are the two upwellings but the river discharge (Binet, 1982) could affect the avaibility of the fish.

The Ivorian and Ghanaian upwellings are non Ekman type upwellings (Houghton, 1976; Bakun, 1978) and a lot of mechanisms are supposed to influence the upwelling activity (Ingham, 1970; Marchal and Picaut, 1977; Picaut, 1983 ; Colin, 1988). So, the coolings of the sea temperature (which is an expression of the upwelling event) is the main way to analyse the upwelling intensity. In addition, two upwellings seasons could be observed off the Côte d'Ivoire and off Ghana.

The 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 a puzzle of observed facts. This paper presents pieces of this puzzle, discusses the available hypotheses and a new hypothesis based on the importance of the second and minor upwelling season on the ecosystem productivity and on the *S. aurita* dynamics.

2. Data and Methods.

Abundance, dynamics and biology of exploited fishes.

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

• 1966 to 1991 in Côte d'Ivoire: catch, effort (days of search), catch per unit of effort (cpue) by fortnight and fishing area ;

• 1972 to 1991 in Ghana: total (annual) catch, effort and cpue (catch per trip).

Catches per unit of effort could be considered as an index of the abundance of the pelagic species.

Length frequency data on sardinellas are available in the Côte d'Ivoire since 1968 and in Ghana since 1963. The data used in the study of the reproductive activity were maturity stage, gonad weight and body weight. These were mainly from two periods, namely: 1964-1970 (in both countries) and 1988-1991 (in Côte d'Ivoire only). The gonado-somatic index ($GSI=PG/aL^n$) was used to follow the spawning activity. Lengths at first maturity were calculated from the logistic relationship.

2. 1 Upwellings intensities.

Data used are as follows:

• data from coastal stations (alongshore sea surface temperature) available for twelve stations (fig.1) in the Côte d'Ivoire and in Ghana (Arfi *et al*, 1991);

• data from merchant ships (offshore sea surface temperature) observations available in the Comprehensive Ocean Atmosphere Data Set from the National Center for Atmospheric Research (USA);

• remote sensing data: the cooling which affects coastal waters could be observed through the thermal infra-red medium of METEOSAT on a daily and five-day basis (FAO, 1992);

• sub-surface temperature profile available in the Côte d'Ivoire since 1983. We have followed the 21°C isotherm depth which correspond in this region with the depth of the thermocline (Merle, 1978).

3. What is the problem ?

3. 1 The upwellings and their relative intensities.

The two upwelling seasons (fig. 2).

This coastal pelagic ecosystem is characterized by two upwelling seasons and two main centers which create a spatial and temporal heterogeneity.

• a minor upwelling season, observed between January and March and more intense in Côte d'Ivoire, especially in the western part, than in Ghana (Arfi *et al.*, 1991).

• a major upwelling season, observed , with a higher intensity, between July and September and which concern the whole coastline. Nevertheless, the continental shelf configuration in the Western Ghana is in favour of a better development of this upwelling.

Intensity of the minor upwelling season (fig. 3).

The minor upwelling season could be, in the Côte d'Ivoire, relatively intense. The 1986, 1987, 1990 minor upwelling seasons were characterized by their high intensities in Côte d'ivoire and we have observed that the rise of the thermocline during these years has been similar to the rise observed during the major upwelling season.

Decrease of the difference between the two upwelling's intensities (fig. 4).

The main point is that the two upwelling seasons have not a similar evolution. During the major upwelling season, the temperature (COADs' data) clearly show an increasing (but not always significant) trend; during the minor upwelling season the contrary is observed. The result is that the difference between the intensity of two upwelling seasons is decreasing (with a significant trend) since the early 1970"s. In both the countries, the difference between the average temperature of the two upwelling seasons is reduced by one degree between 1970 and 1990.

3. 2 Changes in the *S. aurita* fishery.

Instability of S. aurita catch and abundance (fig. 5).

• 1972 : during this year, 90 000 tonnes of *S. aurita* was caught off Ghana although in previous years total catches of the two sardinellas combined were never above 50 000 tonnes;

• 1973-1975 : catches were drastically reduced in 1973 and almost nothing in 1974 and 1975 ;

• 1976-1991: in 1976, the Ghanaian catch had recovered to its former level and fluctuated till 1982. During the same time, catches off Côte d'Ivoire increased by ten fold. Since 1983 high catches and abundance were observed in both countries, and after 1985 the global catches have been at the same level as the high catch of 1972.

Development of S. aurita abundance off the Côte d'Ivoire and changes in the specific composition of catches (fig. 6).

The increase of the catch of *S. aurita* in the Ivorian waters was obtained with a constant effort and the average abundance (cpue) of *S. aurita* observed during the eighties was ten fold higher than in previous years. In Côte d'Ivoire this species became more important than *S. maderensis* and *B. auritus* which have dominated the catches of small pelagics in the sixties and seventies.

Spatial extension of the S. aurita distribution (fig. 7).

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 this country.

A similar but smaller increase was seen in the western part of Ghana. Such changes were not observed for the other small pelagic species in either country.

S. aurita abundance during the two upwelling seasons (fig.8).

In Côte d'Ivoire, the *S. aurita* abundance could be as important during the minor upwelling season than during the major upwelling season, especially in the western part of the country.

Increase of observed and maximum size (fig. 9-10).

The largest modal size of the *S. aurita* caught in Côte d'Ivoire was between 15 and 18 in the 1960"s and early 1970"s. During the 1980"s, this modal size was between 18 and 24. In Ghana, a similar change was observed between the early 1960"s (14-17 cm) and the 1980"s (17-21 cm).

These changes could be also observed for the maximum size found in the catches.

The length at first maturity of the *S. aurita* caught in Côte d'Ivoire seems to have increased from 15 cm in the 1960"s and 1970"s to 18-19 cm in the end of 1980"s.

Changes in spawning activity (fig. 11).

In Côte d'Ivoire, the GSI observed during the minor upwelling season were as large as those of the major upwelling season which has always been considered to be the main spawing season for *S. aurita*. It appears that all the cold periods occuring off Côte d'Ivoire are utilized by *S. aurita* for spawning.

No such dynamical or biological changes were observed for *S. maderensis* or other pelagic species.

4. What are the hypothesis ?

These changes led some researchers to put forward hypothesis on this ecosystem based on observations of the fluctuations in its biotic and abiotic components.

- The decline of *S. aurita* was attributed, at least in part, to the proliferation of *Balistes capriscus*. The rise and collapse of *B. capriscus* was observed between 1970 and 1988. The decline of *S. aurita*, on the other hand, was observed during the proliferation of the biomass of balistes (Caverivière, 1991), but the re-appearance of the former was observed before the decline of latter. Except for their juveniles, these two species do not have the same ecological needs. The hypothesis that there is competition between the two species is therefore untenable. No changes in the biomass of the supposed predator of S. aurita (tuna, scomber) has been furthermore observed.

- Models (Binet, 1982; Cury et Roy, 1987) applied to the pelagic resource of Côte d'Ivoire and Ghana failed to explain the increase in abundance of *S. aurita* in the 1980"s (Pezennec, 1994).

• Increase in wind speed has been supposed to lead to an increase of upwelling off Côte d'Ivoire and Ghana (Roy, 1990). But, these upwellings are not totally 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 relation during the PSF (Pezennec et Bard, 1992). So, increase of wind speed could not have lead to an increase of upwelling, but this environmental factor could lead to an increase of superficial mixing and turbulence which are supposed to increase productivity until the wind speed reaches a value of 6 $m.s^{-1}$ (Cury et Roy, 1989).

• Some authors have explained the increase of abundance of *S.aurita* off Cote d'Ivoire by a change in current system and(or) upwelling intensity in the western and eastern regions off this country (Binet *et al.*, 1991, Herbland et Marchal, 1991). The "current hypothesis" is based on the fact that a possible increase of the westward circulation could have increased the loss of *S. aurita* larvae from the Ghanaian shelf and their retention off Côte d'Ivoire. Hence the recruitment of the Ivorian *S. aurita* should rise. This hypothesis is based on a «displacement toward Côte d'Ivoire of the Ghanaian stock of *S. aurita*» and on a «decrease of *S. aurita* recruitment off Ghana». Following this hypothesis, a decline of *S. aurita* abundance should have been observed off Ghana, but in fact, catches and abundance have increased as much as off Côte d'Ivoire and their quantities have stayed after at a very high level (Pezennec, 1994).

The hypothesis based on a displacement of the Ivorian upwelling main region (from west to east) is based on a short time serie and could not explain the increase of *S. aurita* abundance in the western part of Côte d'Ivoire.

The above hypotheses failed to explain all the dynamical and biological changes, particularly the changes in the Ghanaian part of the ecosystem or the changes in the biology of *S. aurita* (Pezennec, 1994). These changes constitute a puzzle of observed facts which need to be explained by a hypothesis which would take into consideration both the dynamics and the biology of this species.

5. Hypothesis: 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 has been proposed (Pezennec et Bard, 1992). This approach is based on the fact that the Ivorian and Ghanaian coastal pelagic ecosystem is caracterized by two independant upwellings. Nevertheless, the influence of the minor upwelling on the dynamics of coast pelagic species was often neglected. This season has never been took into consideration as an important event for the productivity of the ecosystem.

5. 1 Favourable and unfavourable periods.

In fact, the pelagic species of this ecosystem are facing with an unfavourable period during their life. We are in the ecology field of populations which are in ecosystem characterized by the alternance of favourable and unfavourable period. Which is the most important ? Where the regulation is done ? Where are the threshold effect ?

Some ecological theory insist on the necessity of a global approach to the population-environment system (see Barbault, 1981). If we practice a qualitative approach of the problem of the amount of food, you can have food in profusion, in exces at a global (annual) level but reduced during a critical period or season. In this case, the food production during these period could be seen as a limiting factor.

5. 2 Minor upwelling season and productivity of the pelagic ecosystem.

Studies into the productivity of this ecosystem have shown the importance of the coolings which appear outside the main upwelling season. Zooplanctonic biomass is highly correlated with these coolings (Binet, 1983). The minor upwelling season and all the cooling events outside the main upwelling season occurs in the unfavourable period of the year for the productivity of the pelagic ecosystem and could be compared to a «bottleneck» for this productivity. So, the increase of the importance of the minor upwelling season in the ecosystem could be of great importance.

5. 3 The importance of the minor upwelling season for *Sardinella aurita*.

Two spawning seasons: we have shown that the spawning activity of S. aurita seem to be at the same level during the two upwelling seasons. This is an opportunity for a better exploitation of the ecosystem.

Two favourable areas for the larval survival: the Guinea current creates on the east side of Cape Palmas and Cape Three Points two areas of cyclonic circulation which is in favour of larval retention (Marchal et Picaut, 1977). So, the western part of the Ivorian continental shelf (where the minor upwelling season is the most intense) is an area favourable for the larval survival.

An increase of the observed size: according to Pauly (1984), the increase of the length of fishes caught and of the length at first maturity could correspond with a decrease of factors which limit the growth of fish in an ecosystem (high temperature, food density....).

An increase of the S.aurita abundance off Côte d'Ivoire: the increase of the abundance of S. aurita in the Côte d'Ivoire, first during the major upwelling season, and after during the minor upwelling season could be an illustration of the MacCall's theory (1990) for the density-dependent geographic distribution of the biomass.

5. 4 Transition from a depleted stock to a prosperous stock ? (fig.12).

In the case of the Ivorian seiners, the inter-annual variability of total catch or cpue with effort is very important especially with the lower level of effort. For *S. maderensis*, the years are randomly distributed and cpue and catches are highly variable for mean level of effort (Pezennec, 1994). For *S. aurita*, catches and cpue are distributed in accordance with the state of the resource: before 1981, catches and cpue are were low and increased with fishing effort. After 1980 catches and cpue, much higher than previously, decreased with effort. This figure is in accordance with that from Peterman *et al.* (1979) recalled in Cury (1991). The stock of S. aurita seems to have pass from a depleted state to a prosperous state. The same analysis of the Ghanaian data for *S. aurita* has shown a similar situation (Pezennec, 1994).

6. Conclusion

Differences between the two sardinella species.

We have to emphasize the differences between the two sardinella species in terms of demographic and adaptive strategy: all the changes observed in the dynamics and biology of *S. aurita* were not observed for *S. maderensis*. This is in harmony with the description of the life-history strategies of these two species (Cury et Fontana, 1988): «S. aurita shows a wide plasticity and adaptability to the environmental fluctuations and takes advantages of them». The use of the changes in the relative intensity of the two upwelling seasons could be an illustration of this differences between the two sardinella species.

6. 1 Global and local changes.

The intensity of some of the larger upwelling in the world has increased, this change could be related to global climatic change (Bakun, 1990). Although some of global climatic changes like increase of wind speed (or decrease of rainfall) are observed in this region (Roy, 1990), this has not affected the apparent intensity of the upwelling. In fact, we rather observed a local change: the relative intensity of the two upwellings of this region has changed in a way as to narrow the difference between them.

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Figure 4. Differences between the mean temperatures of the minor upwelling season (PSF) and the major upwelling season (GSF) from 1970 to 1990 (from COADs' data). The linear trends are least-squares method estimates (Côte d'Ivoire p=0.0013; Ghana p=0.039).

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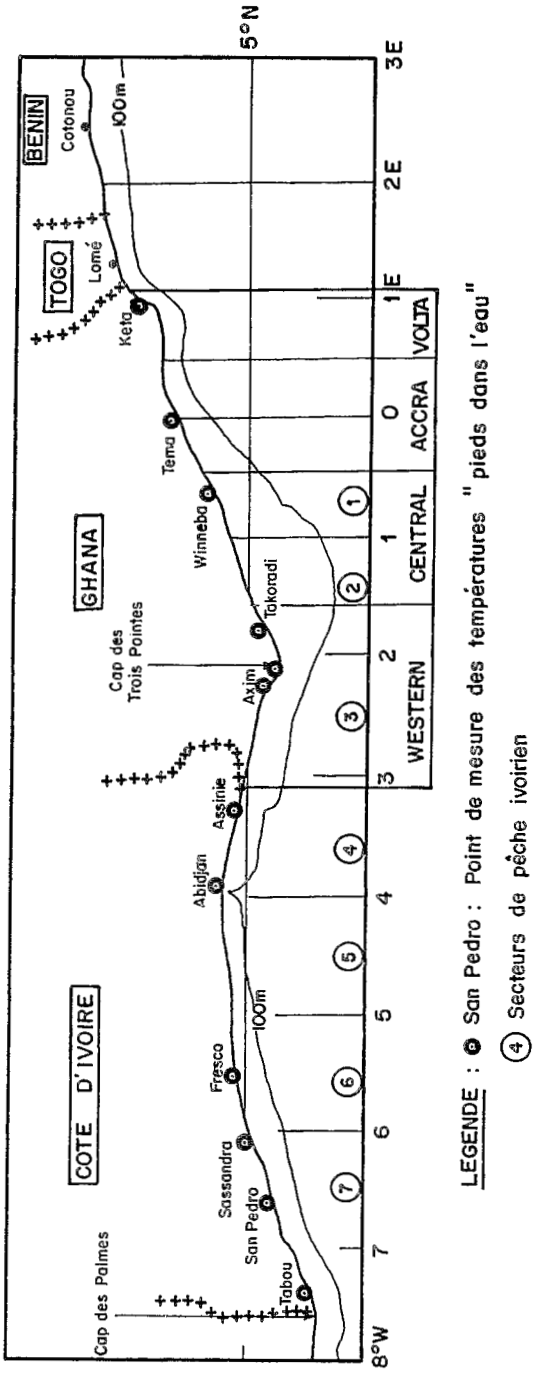

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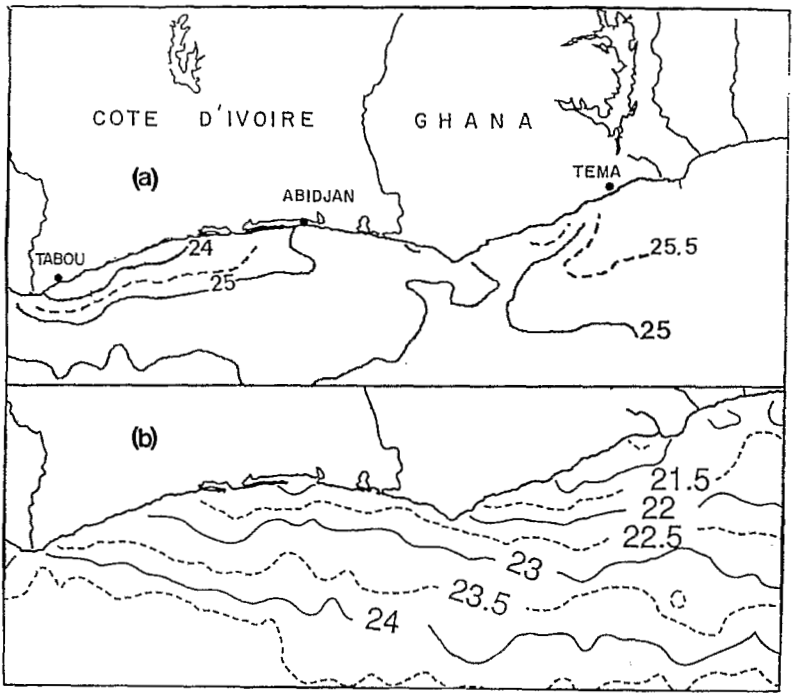

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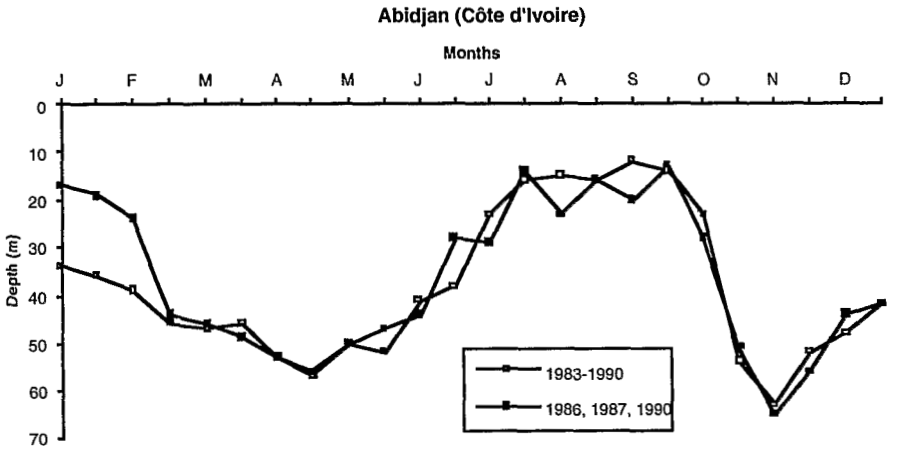

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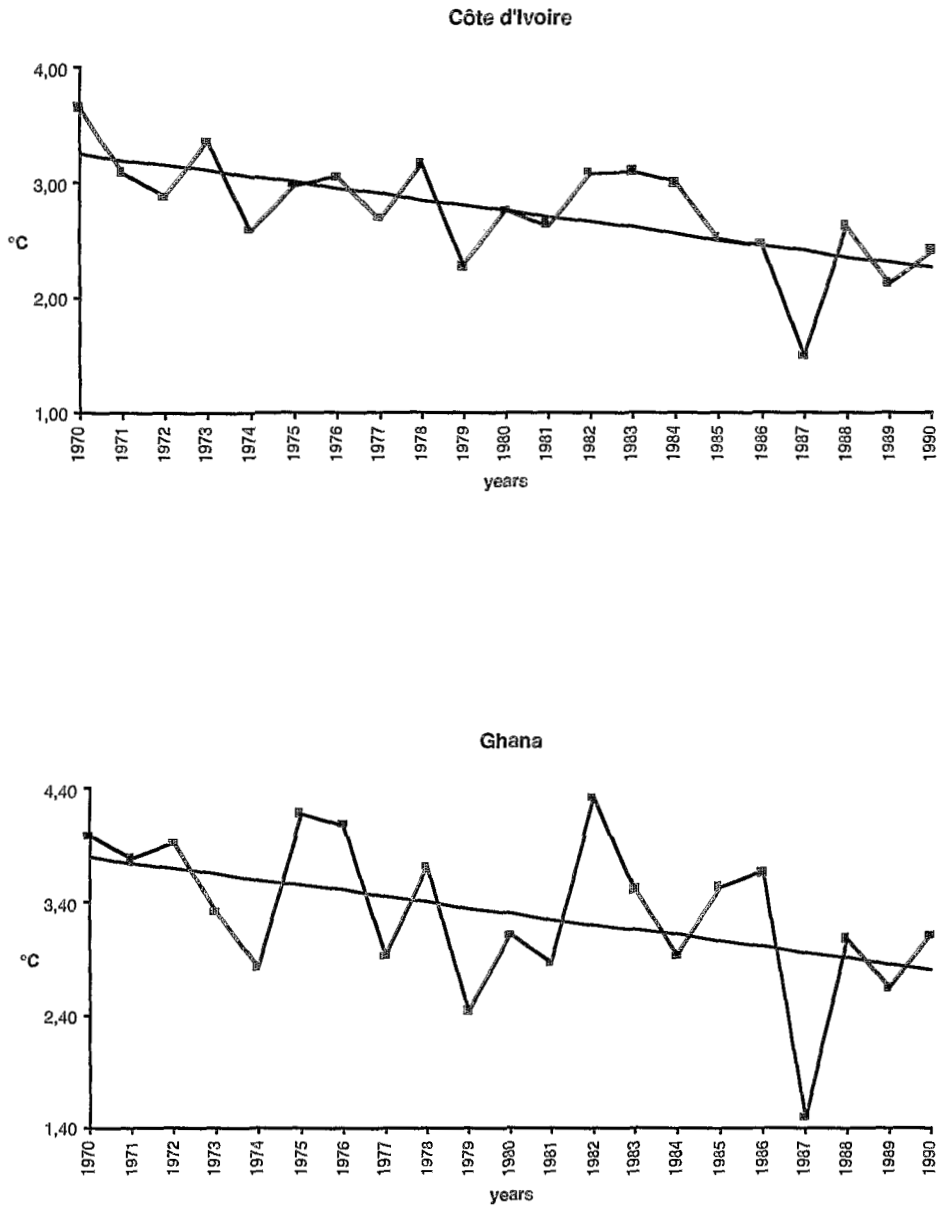


Figure 4. Differences between the mean temperatures of the minor upwelling season (PSF) and the major upwelling season (GSF) from 1970 to 1990 (from COADs' data). The linear trends are least-squares method estimates (Côte d'Ivoire p= 0.0013; Ghana p= 0.039).

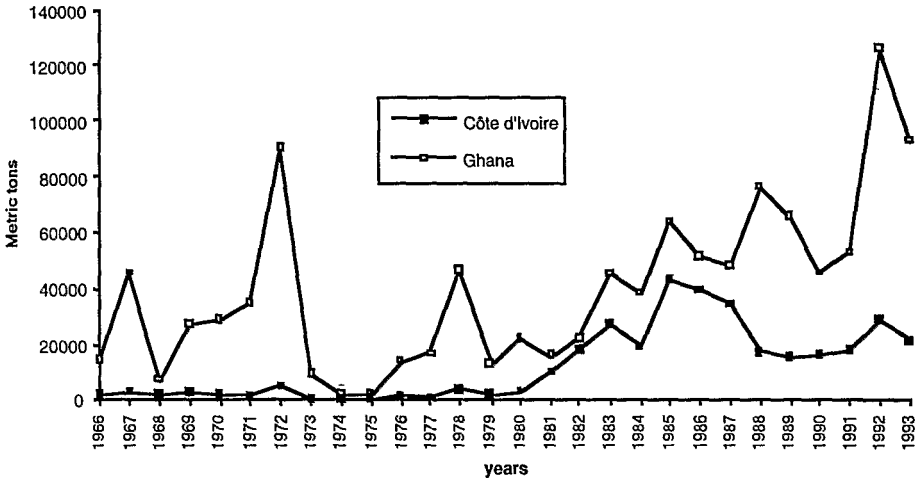


Figure 5. Annual catch of *S. aurita* off the Côte d'Ivoire and off Ghana from 1966 to 1993.

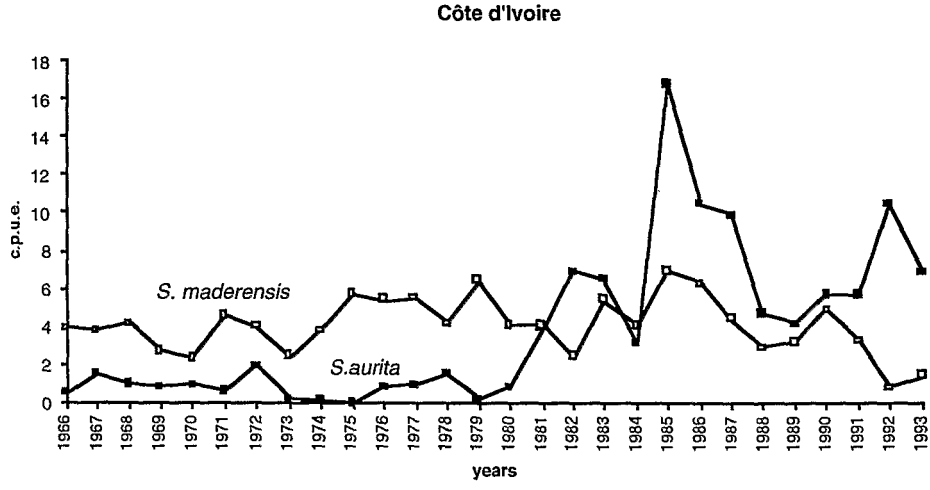


Figure 6. Annual abundance (catch per unit of effort) of *S. aurita* and *S. maderensis* off the Côte d'Ivoire from 1966 to 1993 (metric tonnes per day of search).

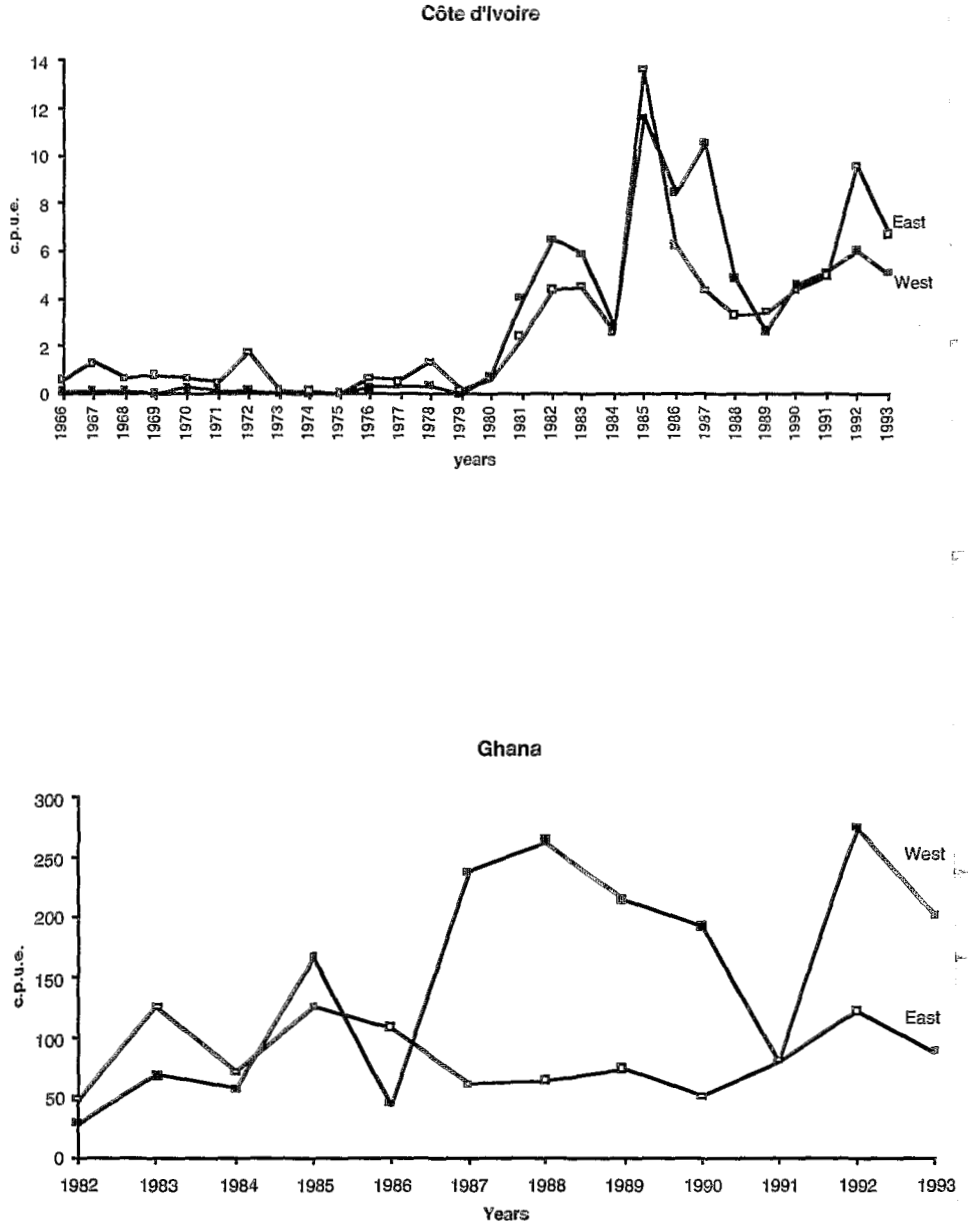
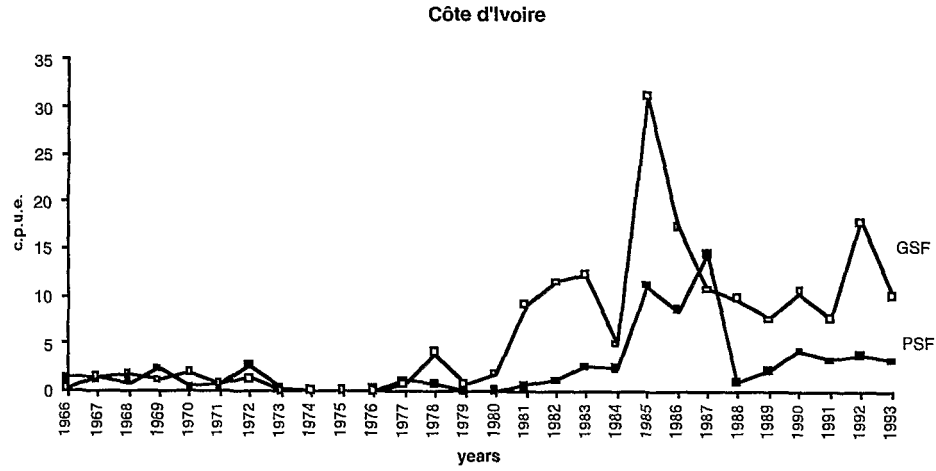


Figure 7. Annual abundance of *S. aurita* off the Western and Eastern parts of the Côte d'Ivoire (1966-1993) and of Ghana (1982-1993). Côte d'Ivoire : metric tonnes per day of search. Ghana : kilos per trip.



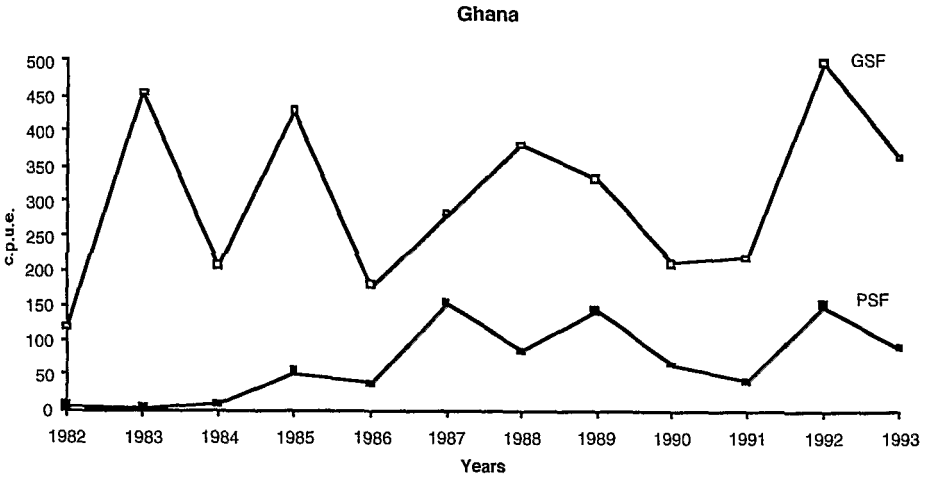
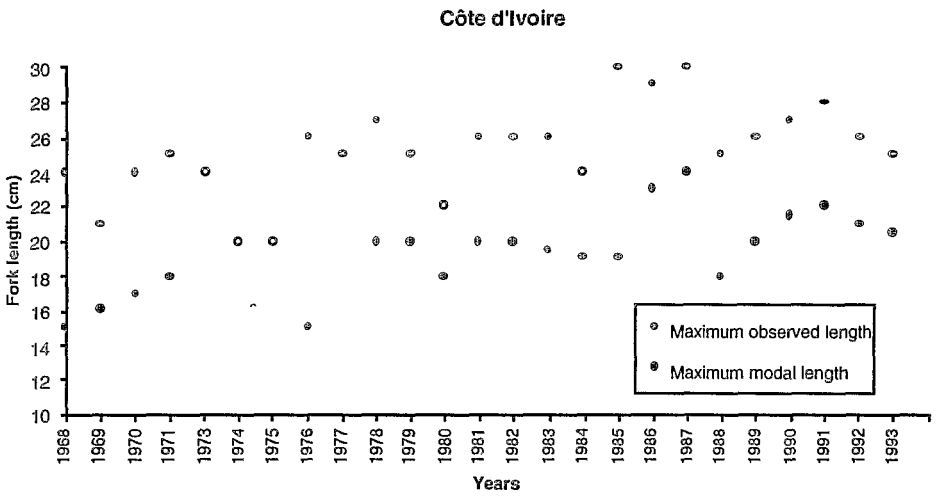


Figure 8. Annual abundance of *S. aurita* during the minor (PSF) and major (GSF) upwelling seasons off the Côte d'Ivoire (1966-1993) and off Ghana (1982-1993).



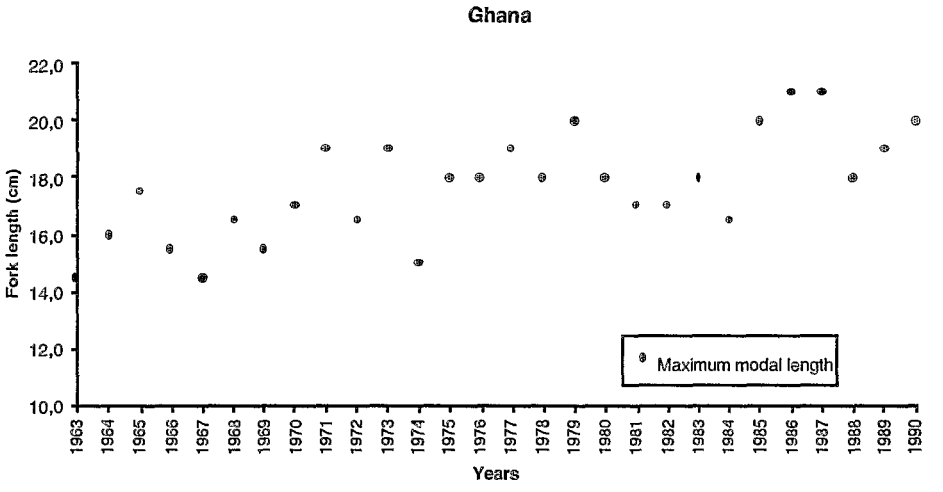
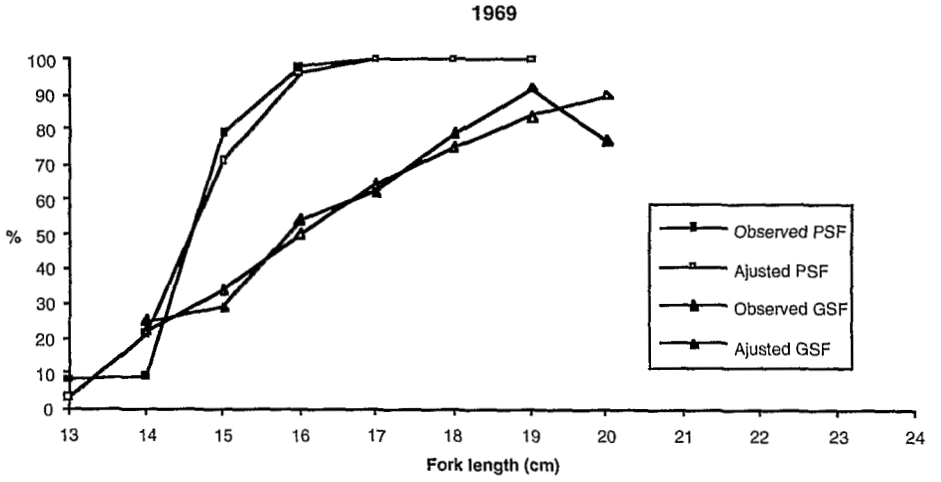


Figure 9. Maximum modal length and maximum observed length (fork length in cm) of the *S. aurita* caught off the Côte d'Ivoire (1968-1993) and off Ghana (1963-1990).



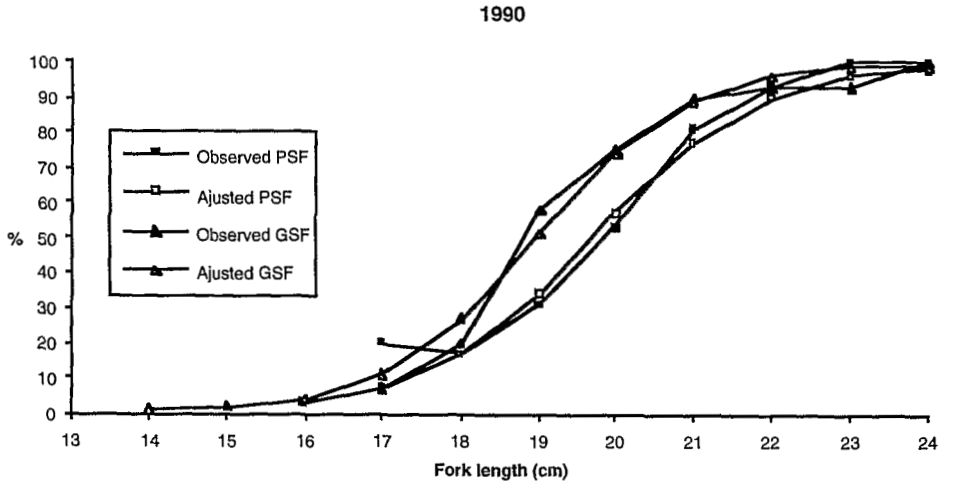


Figure 10. Sexual maturity of the females of *S. aurita* caught off the Côte d'Ivoire during the 1969 and 1990 upwelling seasons : percentage of mature fishes observed and ajusted values (logistic function).

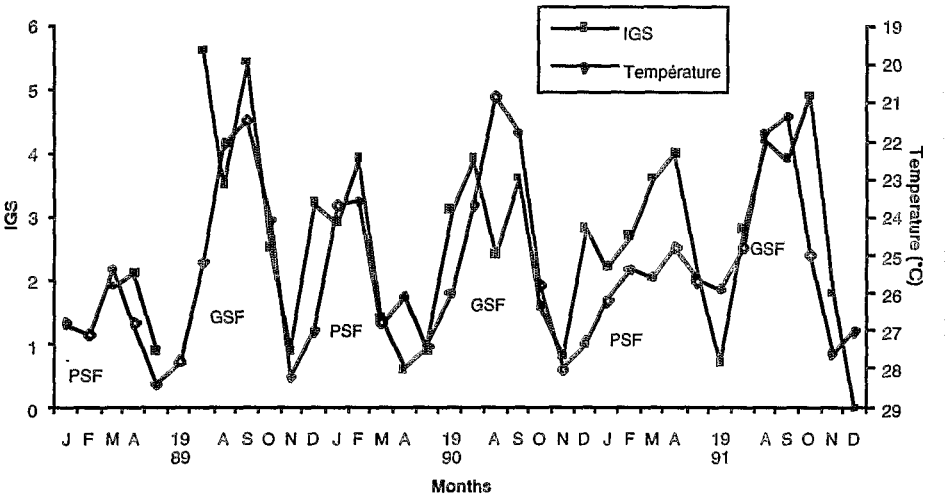
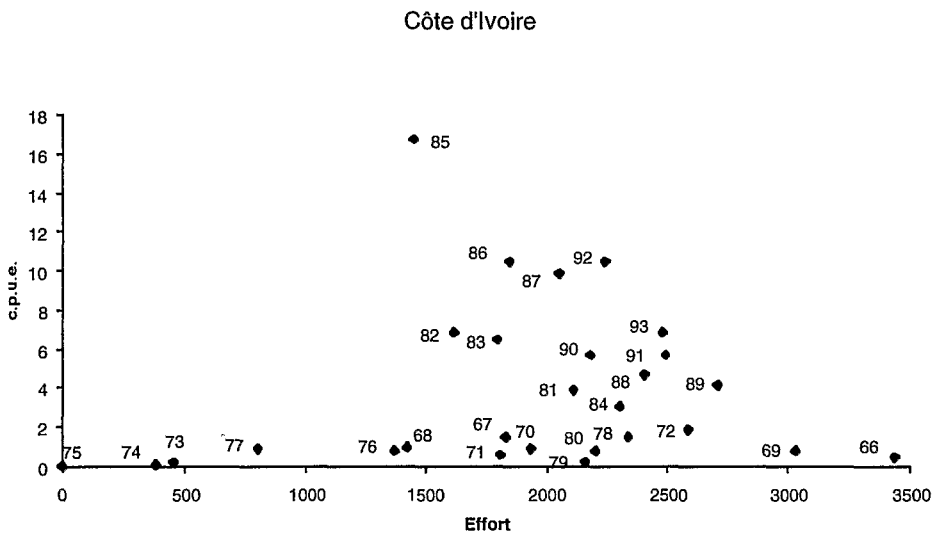


Figure 11. Gonado-somatic index for the *S. aurita* caught off the Côte d'Ivoire and mean temperature (from warmer to colder) in Tabou and Abidjan. Monthly means, 1989-1991.



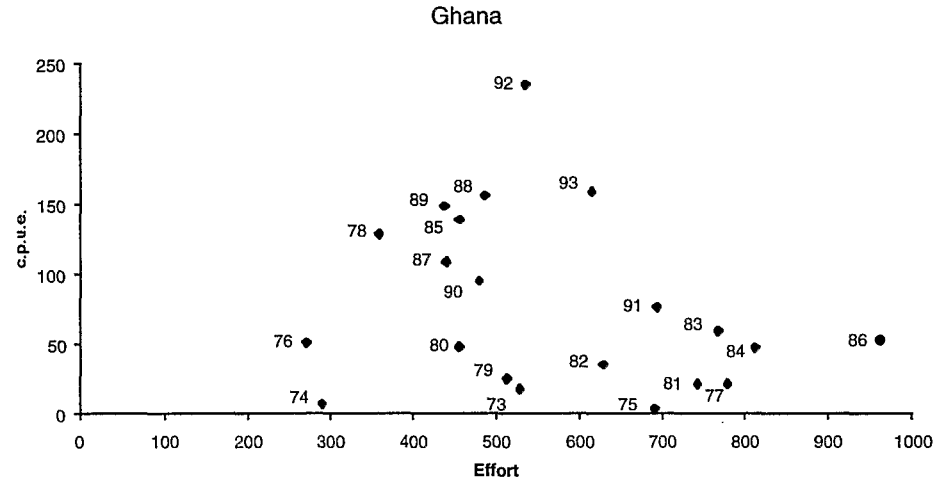


Figure 12. Annual Abundance (catch per unit of effort) of the *S. aurita* off the Côte d'Ivoire and off Ghana and theoritical effort (catch/c.p.u.e.). Côte d'Ivoire : c.p.u.e. metric tonnes per day of search, effort days of search. Ghana : c.p.u.e. kilos per trip, effort trips.