The Gulf of Guinea Large Marine Ecosystem
J.M. McGlade, P. Cury, K.A. Koranteng and N.J. Hardman-Mountford (Editors)

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Environmental and Resource Variability off Northwest Africa and in the Gulf of Guinea: A Review

C. Roy, P. Cury, P. Fréon and H. Demarcq

Abstract

Environmental monitoring off West Africa relies mainly on a set of coastal stations, on the COADS data base and on satellite imagery. This provides useful information on a limited set of variables such as SST and wind. These variables can be related to fish population dynamics at different scales of observation including short-term changes in fish availability, year to year abundance or lower frequency regime shifts. Tools such as multiple time series analysis, GAM (General Additive Models) and IBM (Individual Based Models) can help to track time lags, non-linear relationships and discontinuities that exist between environmental variables and fish populations. These methods can help to further understand ecological processes in relation to environmental variability. Relatively few oceanographic surveys have been done off West Africa and the existing oceanographic data are difficult to access. As new information on environment, resources, fisheries and their interaction are needed for management purposes and research, particular attention should be devoted to process oriented studies. Given constraints on human and financial resources, the challenge is to achieve an appropriate balance between monitoring and process-oriented studies.

Introduction

Scales of observation and scales of study are a subject of interest in marine as well as in terrestrial ecology (Steele 1995). Variability may affect ecological processes on very different scales ranging from micro-turbulence that affects encountering rates between plankton and fish larvae, to global climatic changes which might strengthen upwelling intensity and therefore global ecosystem productivity (Bakun1990). Scales of observation and of a particular studies might be different (disconnected). For example, a particular process might act on a very local scale yet be observable on a more global scale (e.g. recruitment may be due to a very small fraction of the parental spawning success in a particular retention area but observable at the scale of the whole fishery). West African examples of short-term, medium-term and long-term changes and their impact on fisheries are presented in this paper. When referring to short-term we consider changes in fish availability from one fortnight/month to the next. Seasonal or inter-annual variability affects fish abundance and longer time periods may play a significant role in changing reproductive patterns and decadal variations in fish abundance. A review of previous work done in West-Africa is presented, emphasizing the importance of addressing proper scales when studying climate and fisheries.

Monitoring Environmental Variability

In most West-African countries, oceanography is the responsibility of the national fisheries research institutes and consequently limited financial and human resources have been allocated to support environmental monitoring and research. Oceanographic research vessels do exist in many West-African countries, but due to lack of modern scientific equipment, trained technicians and financial support, alternative ways to gather environmental information have to be considered.

A brief review of the available environmental data

In the late 1950s, ORSTOM set up a network of coastal stations in Senegal, Côte d'Ivoire and Congo. At each station, Sea Surface Temperature (SST) is measured daily from the beach or a wharf using a bucket and a thermometer. Some of these stations are still operating and continuous records of SST are now available for the past 30 or 40 years. Salinity and nutrient data were also collected at some stations, but data density is very low. In Côte d'Ivoire and Congo, time series of plankton displacement volume are also available from 1969 to 1981 (Binet 1983). In the late 1960s, the MFRD of Ghana also implemented a set of coastal stations along the coast. Since 1968, MFRD has also maintained a weekly transect, consisting of four stations from the coast to the 1000m isobath. Salinity, temperature, oxygen and zooplankton samples are collected at each station (Mensah 1995; Koranteng 1998).

Another source of information is provided by meteorological data collected at several airports along the coast of West Africa. It has been shown that the Dakar-Yoff (Senegal) and Nouadhibou (Mauritania) airports, each being located on a cape, provide useful data for assessing wind variability over the coastal domain. These wind data are often used to calculate an index of the upwelling intensity (Arfi 1985; Roy 1989). This index called 'Coastal Upwelling Index' (CUI) is the offshore component of the wind induced Ekman transport (Bakun 1973). CUI has been used to characterize the upwelling strength on both seasonal and interannual scales.

The Comprehensive Ocean Atmosphere Data Set (COADS) provides an alternative when limited information is available. COADS summarizes over 100 million surface meteorological observations collected by ships of opportunity and other platforms over the world oceans which have been quality controlled and put into a consistent format (Woodruff *et al.* 1987). This dataset is the most complete record of surface marine climate to date. It has world-wide coverage and the earliest data dates back to 1854. The five CD-ROMs and the software developed by the CEOS project (Roy and Mendelssohn 1998) provide an easy way to extract time series of SST, wind, air temperature and atmospheric pressure along the ship tracks located off the west African coast.

The COADS dataset appears to be a useful surrogate when oceanographic data are not available. It is also well suited for comparative analyses between different areas, as one can expect the data to be homogeneous over large areas. Despite some biases such as a spurious trend in the wind and a shift in SST in the early 1940s, useful information on the long-term variability of the environment can be developed using COADS (Roy and Mendelssohn 1998). Satellite data such as METEOSAT IR or NOAA/AVHRR images are also of special interest for analysing the coastal dynamics of the upwelling system. Several long-term databases, going back to the early 1980s, exist for the Atlantic ocean : the CORSA from JRC (Nykjaer and Van Camp 1994) or the IR METEOSAT images from UTIS/ISRA (Demarcq and Citeau 1995). NOAA MCSST or PATHFINDER dataset also provides useful information for large-scale studies.

Oceanographic data were collected over North West Africa during the CINECA and JOINT experiments which took place in the late 1970s (Hempel1982). The data collected during these international projects remain the most comprehensive oceanographic dataset collected off Northwest Africa. Some oceanographic data are collected during fishery surveys (national or co-operative) but most often these are difficult to access. In some countries, oceanographic surveys are performed under bilateral agreement or fishing counterpart. Off Senegal, the CIRSEN project lasted for three years (1985-1988) and was designed to provide oceanographic data over the whole continental shelf.

In summary, continuous environmental monitoring off West Africa has been limited. However time series are available for a couple of parameters (wind, SST) for several decades. These time series provide useful basic information on the local marine environment and its variability.

Environmental variability off West Africa

Off West-Africa, the density of data collected by ships of opportunity is high as main ship tracks connecting the northern and the southern hemispheres are located within a few miles off the coast. From Morocco to Ghana, continuous monthly SST and wind time series can be constructed using the COADS dataset. Using COADS, a comparison of the seasonal dynamics of the West-African coastal ecosystems was performed using the mean seasonal cycle of SST and wind-derived variables such as upwelling index and wind mixing index (Roy 1991). It provided useful insight into the latitudinal and seasonal variability of the main physical forcing factors of the West-African coastal upwelling (Table 10-1). The resulting data have been used in several studies, which related small pelagic fish reproductive strategy and the environment (Roy *et al.* 1989, 1992; Fréon *et al.* 1997; Shin *et al.* 1998).

Along the West African coast, COADS SST anomalies during the upwelling season highlight the main patterns of upwelling activity over the last 45 years (Figure 10-1, colour plate). South of 20°N, interannual variability is well defined and one of the major features is a pronounced cooling that occurred from 1971 to 1977, followed by a warming that lasted for several years, until 1984. These alternations of cold/warm periods have been well documented using other data sources (Binet 1988; Roy 1989; Koranteng 1998; Koranteng and McGlade, this volume) and they have had important ecological consequences. North of 25°N, the intensity of SST interannual variability during the upwelling season appears to be weaker than further south.

Upwelling dynamics off Senegal

Upwelling off Senegal starts to develop in late November as a consequence of the onset of the trade-winds which blow quite steadily from November through May. Along the coast, SST drops within a month from 28°C to less than 18°C. SST can be as low as 14°C in upwelling centres such as the tip of the Cape-Vert peninsula or the northern coast of Senegal. The negative correlation between CUI and SST suggests that local wind is the dominant forcing

Location	Upwelling duration	SST (°C)			Wind Speed ($m.s^{-1}$)			CUI ($m^3.s^{-1}.m^{-1}$)		
		min.	max.	mean	min.	max.	mean	min.	max.	mean
34°N-36°N	April-August	16.21	22.37	19.03	5.18	6.44	5.77	0.04	0.35	0.19
32°N-34°N	April-August	16.80	22.25	19.36	4.96	6.31	5.75	0.11	0.71	0.37
30°N-32°N	March-August	17.14	21.30	19.12	5.18	7.91	6.73	0.41	1.39	0.87
28°N-30°N	March-August	17.63	21.65	19.47	5.29	7.92	6.47	0.31	1.05	0.70
26°N-28°N	Permanent	18.48	22.40	20.27	5.47	8.59	6.79	0.54	1.53	0.92
24°N-26°N	Permanent	18.57	22.03	20.15	5.50	7.87	6.68	0.60	1.45	0.98
22°N-24°N	Permanent	18.28	21.38	19.66	5.58	8.16	7.00	0.78	1.73	1.28
20°N-22°N	Permanent	18.22	22.62	19.88	5.73	8.52	7.10	0.92	2.18	1.52
18°N-20°N	October-June	18.92	26.38	21.89	4.54	7.41	6.21	0.92	2.15	1.48
16°N-18°N	October-June	19.54	27.76	23.22	4.15	6.66	5.51	0.52	2.11	1.37
14°N-16°N	December-May	19.68	28.09	24.05	3.62	5.71	4.86	0.21	1.96	1.16
12°N-14°N	December-May	20.25	28.37	24.83	2.83	5.06	4.16	-0.14	1.69	0.91
10°N-12°N	January-April	22.18	28.25	25.91	2.12	5.41	3.40	0.07	1.04	0.54

Table 10-1 Main environmental characteristics of the Canary current upwelling ecosystem (derived from COADS dataset).

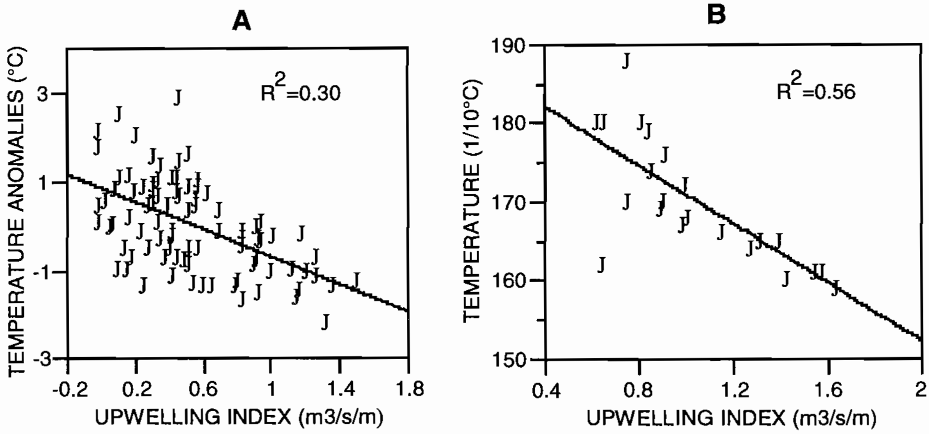


Figure 10-2 Relationship between SST anomalies and upwelling index (A) and SST and upwelling index (B) at Dakar Thiaroye, 1966-1987.

factor of the upwelling (Roy 1989). Stronger than average trade winds lead to enhanced coastal upwelling and cold SST (Figure 10-2). This simple model of the response of upwelling to wind shows that data collected at coastal stations can be used to characterise the interannual variability of the Senegalese upwelling. Both coastal SST and CUI data have been widely used to relate fish population dynamics to the environment (Fréon 1983; Cury and Roy 1988, 1989; Roy 1998).

Spatial dynamics of the upwelling from METEOSAT data

Sea Surface Temperature (SST) is routinely computed using METEOSAT satellite infrared data. METEOSAT's half-hourly observation frequency allows production of daily images with low cloud contamination. Despite the limitation of METEOSAT IR data (low spatial resolution, low accuracy), a continuous time-series of images with a time step of several days can be constructed; these time-series are extremely useful for studies of the dynamics of the coastal upwelling off West Africa.

The satellite data are initially processed on a daily basis; the initial spatial resolution (5 km) as well as the thermal resolution (0.5 °C) is preserved. As a compromise between the variability of the upwelling process and the quantity of data to be analysed, daily images are averaged over 5 days time periods without altering the 5 km spatial resolution (Demarcq and Citeau 1995). These 5 day composites are then used to derive structural parameters such as the value and the position of the near-coastal upwelling maximum. These data are also used to derive a satellite based upwelling index (Figure 10-3, colour plate) and to study SST gradient over the shelf in order to identify areas where retention may be favoured.

Short-term Environmental Changes and Pelagic Fish Availability

Availability of sardinellas off Côte d'Ivoire and associated environmental conditions

Availability of pelagic fish might be associated with instant or short-term environmental processes as fish act to seek food in their proximate environment. The fishery off Côte d'Ivoire occurs in a region with two upwelling seasons, a smaller one around January and a larger one from June to September. Mendelssohn and Cury (1987) primary goal was to model the relative impact of the environment on the availability of pelagic species off Côte d'Ivoire and the manner in which the environment affects the dynamics of catch per unit effort for these species on time scales as short as two weeks. Using multivariate time series methods, a fortnightly abundance index of the Ivorian coastal pelagic species was related to SST in the areas in which the fishery operates. This multivariate autoregressive model is able to explain 43% of the observed variance in catch per unit effort (cpue, in tonnes per unit of search time) from 1966 to 1982. The following AR model was used:

$$\begin{aligned} \text{Lncpue}(t) = {} & 0.248\,\text{Lncpue}(t-1) + 0.254\,\text{Lncpue}(t-2) + 0.162\,\text{Lncpue}(t-4) + \\ & 0.143\,\text{Lncpue}(t-24) - 0.143\,\text{SST}(t-1) + 0.112\,\text{SST}(t-2) + \\ & 0.144\,\text{SST}(t-17) \end{aligned} \qquad \textbf{Eq. 10-1}$$

where $\text{Lncpue}(t) = \text{LOG}(\text{cpue}(t) + 0.05)$.

The model shows that, all things being equal, cpue will show some persistence on its own; at low levels it will tend to remain low and conversely so for high levels remain high. From the model estimates it appears that a drop in SST from two to one fortnight previously provides an increase in cpue. The sharper the drop, the greater the effect on cpue. Binet (1976) presented results that show a correlation between a drop in SST and an increase in zooplankton biomass a fortnight later (Figure 10-4). Binet (1983) also suggested that cold

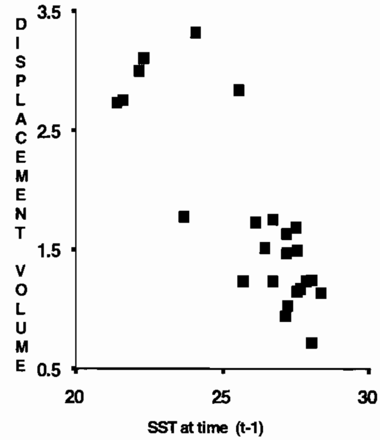


Figure 10-4 Mean plankton displacement volume (ml/m3) per fortnight as a function of SST off Cote d'Ivoire from 1966 to 1990; (plankton data from D.Binet).

waters tend to increase the aggregation of zooplankton at the surface and, hence to aggregate fish as catch per set tends to increase with plankton volume (Figure 10-5). Availability of fish depends on food availability as fish tend to form larger schools when the environmental conditions are favourable. Pelagic species probably come to the surface more and school more when there is abundant zooplankton biomass around which to aggregate. Variables such as SST are not sufficient to explain the evolution of cpue particularly when measured at the same time period as the catch. SST acts as a surrogate variable for oceanographic and biological processes that create favourable conditions for the pelagic fish species. Therefore it is the dynamics of the variables between periods that are important, not a static value in one time period. Similar results were found in tuna in the Gulf of Guinea (Mendelssohn and Roy 1986; Stretta 1991), illustrating the importance of considering short-term process when studying fish availability.

Catch per set of pelagic fish in Senegal and Côte d'Ivoire and associated environmental conditions

Fish school size appears to be highly variable on extremely short time periods (from hour to hour) or on larger time scales (seasonal or inter-annual). This has significant consequences for the availability of fish to the fishers. Fish school size can be measured directly using acoustics or indirectly using fisheries data. Many factors can affect the catch per set of a purse-seiner: the size of the net, the boat-loading capacity, the fishers strategy, the size of the schools. However it appears that the catch per set can provide a reliable index of mean school size and abundance. The mean catches per set of Senegalese (Fréon 1991) and Ivorian seiners were calculated per month from 1969 to 1987 and per fortnight from 1966 to 1990. As noted previously there are two upwelling seasons off Côte d'Ivoire, however small pelagic fish are caught all year round. Catch per set for the pelagic fisheries have been calculated in Senegal and Côte d'Ivoire on different scales of interest for the fisheries (from a fortnightly mean to an annual mean). When comparing the two data sets it appears that larger schools are fished in Senegal compared to those fished in Côte d'Ivoire: the average catch per set is around 9.7 tonnes in Senegal and only 4.6 tonnes in Côte d'Ivoire. In both countries the catch per set exhibits large seasonal fluctuations which can be related to the SST patterns (Figure 10-6). Thus it appears that larger catches per set are observed during the upwelling seasons. When calculating annual mean indices, it appears that there exists a strong correlation between cpue (in tonnes per unit of search time) and catch per set (in tonnes) (Figure 10-7). Catch per set roughly reflects fish school size and is strongly related to environmental fluctuations and probably to food availability. Changes in fish school size would depend primarily on the productivity of the upwelling area; a more productive area like Senegal would be able to sustain larger pelagic fish school sizes compared to Côte d'Ivoire. Mean fish school size appears to be related to the seasonal environmental patterns in the way that during the more productive periods, probably corresponding to higher food density observable during the upwelling seasons, fish tend to form larger schools (Figure 10-6) (Blaxter and Hunter 1982). On the whole, this has an effect on fisheries as catch per set and cpue appear to be strongly correlated on an annual scale (Fréon 1991).

Seasonal or Inter-annual Environmental Changes and Pelagic Fish Abundance

Pelagic fish abundance and surplus production models

Conventional surplus production models for stock assessment use only one input variable: the fishing effort. These models are not suitable for most of the pelagic stocks because fishing effort (E) variations only explain a small part of the total variability of annual production and catch per unit of effort (CPUE). In such a so called "unstable stock", residual variability often originates from the influence of environmental phenomena, which affects either the abundance (surplus production) or catchability of a stock. Fréon (1986, 1989) gave a theoretical basis for production models incorporating an environmental variable as a second independent variable in addition to fishing effort.

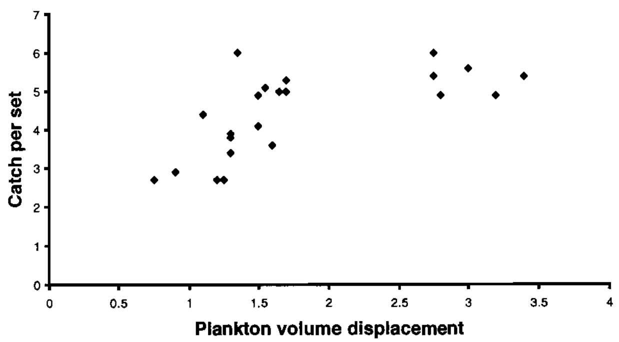
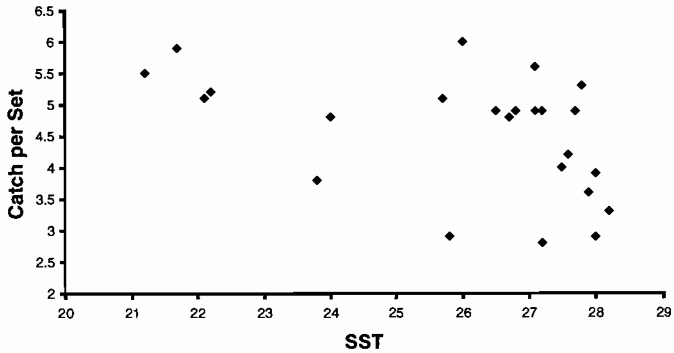


Figure 10-5 Catch per set as a function of plankton volume displacement per fortnight from 1966 to 1990; (data from CROA and D. Binet).



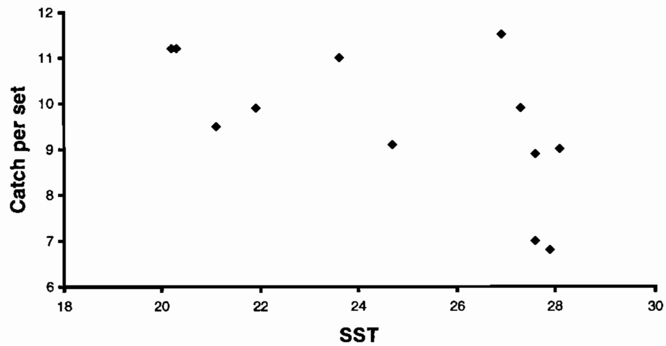


Figure 10-6 Mean total pelagic catch per set (tons/searching day) off Côte d'Ivoire and Senegal per fortnight and per month from 1966 to 1990 and 1969 to 1987.

The influence of this variable has been considered at two levels: on stock abundance and on stock catchability. For each case the conventional linear and exponential models (and sometimes the generalised model) are considered. The CLIMPROD software is an expert-system which first helps the user to select a corresponding model according to objective criteria. Then CLIMPROD fits the selected model using a non-linear regression routine and tries to assess the fit with parametric and non-parametric tests before presenting tables and graphs of the results in EXCEL format (Fréon *et al.* 1993).

This approach has been successfully applied to several pelagic stocks in Senegal, Côte d'Ivoire and Morocco (Fréon 1986) and also in Chile and Peru. In the case of Senegal, the interannual variations of the upwelling index are empirically related to the abundance of the stock (in addition to CPUE), while in the case of the *Sardina pilchardus* stock off the northern part of Morocco they are related to the catchability of this species. In the case of northern Morocco, the environmental effect is mainly on the catchability and the conventional Fox's exponential model was modified in order to let the coefficient of catchability, q, vary according to an upwelling index.

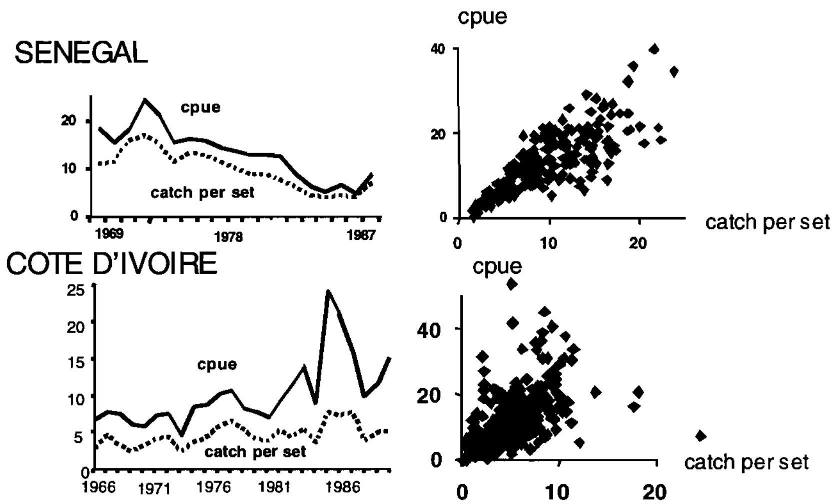


Figure 10-7 Annual cpue and catch per set in Senegal and Côte d'Ivoire from 1969 to 1987 and 1966 to 1990 (left). Cpue versus catch per set in Senegal and Côte d'Ivoire per month and per fortnight (right).

Using the same approach Cury and Roy (1987) analysed the catch and CPUE off Côte d'Ivoire by introducing SST into a Fox production model, but here the environmental effect was found to be on the abundance of the stock rather than on its catchability.

Optimal environmental window and pelagic fish recruitment

A dome shape relationship was found between annual recruitment indices and upwelling intensity using GAM (Generalized Additive Models) for different pelagic species such as sardines and anchovies in different upwelling systems (Cury and Roy 1989; Cury *et al.* 1995, Serra *et al.* 1998) (Figure 10-8). This model suggests that very weak winds may have a negative effect on recruitment by decreasing the production of food for larvae, while strong turbulence generated by high wind speeds has a negative effect on larval survival by desegregating food and larvae patches. This dome shaped relationship is known as the OEW (Optimal Environmental Window) (Cury *et al.* 1995; Bakun 1996). The value of 5-6 $m.s^{-1}$ was found to be a threshold common to many ecosystems and species. The OEW explains approximately 20-25% of the recruitment variance in upwelling areas. For a non-Ekman type upwelling such as occurs in Côte d'Ivoire, the relationships between recruitment and upwelling intensity appears to be linear as the winds appear to be lower than the threshold value of 5-6 m s^{-1} (Figure 10-11).

Seasonal fish migration off Senegal and Mauritania

Many pelagic and demersal species migrate seasonally between Senegal and Mauritania. The appearance of a migrant population of thiof (*Epinephelus aeneus*) along the north coast of

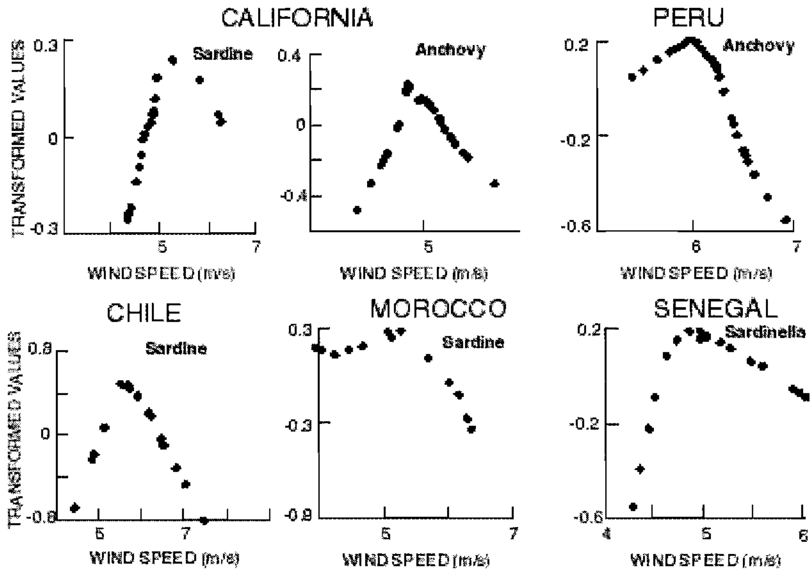


Figure 10-8 The relationship between recruitment and wind speed in several upwelling ecosystems.

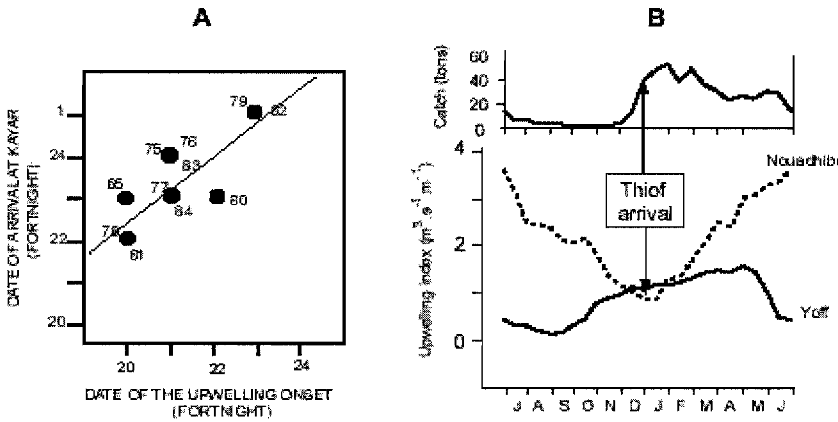


Figure 10-9 **a**-the relationship between the seasonal arrival of Thiof at Kayar and the onset of the upwelling (1975-1985). **b**-Mean monthly upwelling (m3/s/m) indices at Yoff (Senegal) and Nouadhibou (Mauritania) and mean monthly thiof catches (tons) at Kayar (adapted from Cury and Roy 1988).

Senegal is related to the onset of the Senegalese upwelling which takes place from November to May (Cury and Roy 1988).

Anomalies of SST data collected at coastal stations were used to characterise the upwelling intensity. Using cpue in the two main landing ports (Saint-Louis and Kayar), a mean lag of about one month was found between the occurrence of the upwelling and the arrival of the thiof off Kayar (Figure 10-9a). The migration of the thiof from Mauritania to Senegal appears to be not only related to the onset of the Senegalese upwelling but is also linked to the relaxation of the upwelling off northern Mauritania (Figure 10-9b). Fish species also seem to migrate seasonally in order to take advantage of the most productive areas (Fréon 1986; Pauly 1994).

Long-term Changes and Pelagic Fish Dynamics

Long-term changes in pelagic fish abundance off Côte d'Ivoire and Ghana and associated environmental changes

The analysis of several environmental time series off Côte d'Ivoire and Ghana, Koranteng and Pézennec (1998) showed that the mean annual wind speed exhibits a significant positive trend from 1966 to 1990. However when taking into consideration the annual mean SST, the minor and the major upwelling seasons show opposite trends during the same time period. As a result the difference between the characteristic minimum temperatures of the two upwelling seasons decreased by about one degree between 1970 and 1990 in both countries (Koranteng and Pézennec 1998). Meanwhile one of the two species of sardinella, *Sardinella aurita*, showed a transition from a depleted to a prosperous state as cpue increased from 0.8 to 7.2 t/day before and after 1980 (Pézennec and Bard 1992). The minor upwelling occured during an environmentally unfavourable period for the global productivity of the pelagic ecosystem. The minor upwelling, which started to intensify in the late 1970s, looks to have played a major role in driving the abundance of *Sardinella aurita* (Figure 10-10). It seems to act as a 'bottleneck', with the duration and strength of the minor upwelling appearing to significantly affect recruitment of the *Sardinella* population. This example illustrates quite well the importance of considering not only the main environmental events but also the minor events that can affect fish populations.

Long-term changes in fish distribution

In the southern part of the Canary current a large sardine fishery has developed off the Western Sahara which did not exist before 1965. Two southward expansions of the sardine (*Sardina pilchardus*) occurred 23 years apart and are correlated to multi-year periods of trade wind strengthening which occurred in 1972-1975, in 1982 and from 1991 onward (Binet et al., 1998). The dynamics of the upwelling, computed from satellite data (Meteosat), for the period 1984-1994 also reveals spatial changes in recent years (Figure 10-3) that are associated with sardine availability to the small scale fisheries off Senegal (Demarcq 1998).

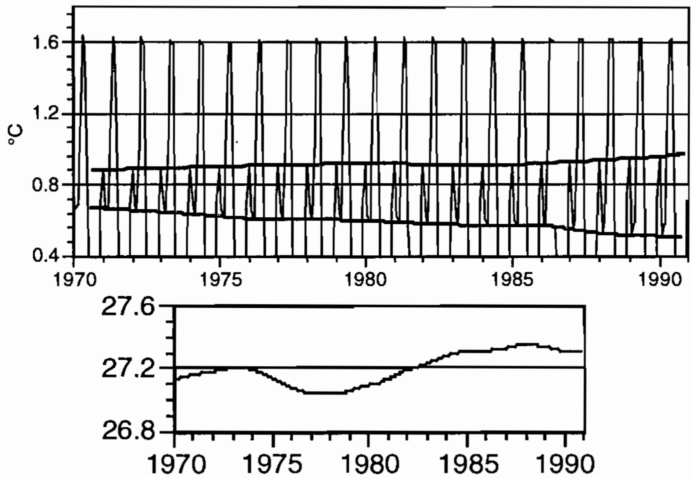


Figure 10-10 Seasonal component (upper) and long term trend (lower) of a decomposition of the SST signal off western Côte d'Ivoire (from Roy 1995).

Fish reproductive strategy

When comparing small pelagic fish reproductive strategies in several areas within the Canary and Guinea Current ecosystems, differences in timing are observed (Roy *et al.* 1989, 1992). In some areas spawning occurs during the upwelling season (Senegal, Côte d'Ivoire) and in other areas outside the upwelling season (Morocco) or when upwelling activity reaches a minimum (Sahara). The mean environmental conditions (wind speed and CUI) during the spawning season in the main spawning grounds were calculated using data extracted from COADS. It appears that there is no apparent relationship between the upwelling intensity and reproduction (Figure 10-11) but rather a striking correspondence between the timing of reproduction and the occurrence of a composite-average wind speed of about 5-6 m s^{-1} (Roy *et al.* 1992). This range in wind speed corresponds to the optimal wind conditions as defined by the OEW. The correspondence between spawning peaks and the 5-6 m.s-1 wind speed illustrates the long-term adaptation of small pelagic fish reproductive strategies to the environment.

Upwelling and retention

Off Senegal, there is a surprising correlation between spawning of several major fish species and the upwelling process. Intense spawning is concentrated in late spring south of Cape Vert. Using satellite data and surface oceanographic measurements, it is shown that the surface distribution of several environmental parameters in this location is quite unusual for an upwelling area. Sea surface temperature is minimum over the shelf and increases toward both offshore and coastal directions; the distribution of chlorophyll is also contrasted with a being the result of a 'double cell' structure of the upwelling vertical circulation (Figure 10-12) (Roy 1998):

- a first cell is located on the shelf-break; it is the main upwelling cell that brings cold and nutrient rich subsurface water to the surface.

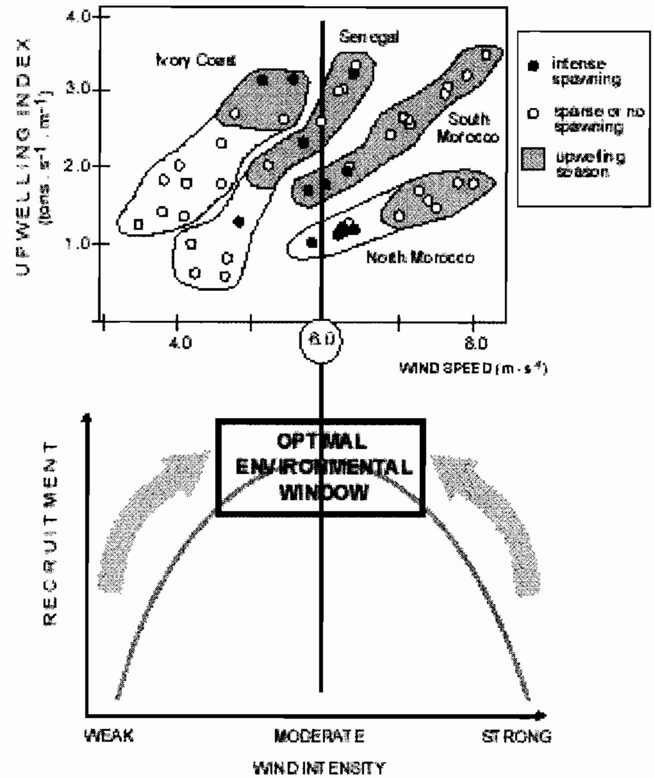


Figure 10-11 The spawning activity of sardine and sardinellas in relation to wind speed and upwelling off West-Africa : north Morocco (30°N to 27°N), south Morocco (26°N to 22°N), Senegal (15°N to 9°N) and Côte d'Ivoire (5°N, 2°W to 1°E). Mean monthly upwelling indices ($tons.s^{-1}.m^{-1}$) are plotted against mean monthly wind speed ($m.s^{-1}$); wind speed and upwelling indices were calculated using COADS. The upwelling seasons are shaded and months corresponding to intense spawning are indicated by a black dot. Note that black dots (intense spawning) for all regions are
With this type of configuration, upwelling and retention can occur simultaneously and act together to provide a favourable reproductive habitat. In other areas (e.g. Côte d'Ivoire and Ghana, the southern coast of Morocco, South-Africa) there is also a co-occurrence between spawning and upwelling. In these ecosystems, similar physical processes must allow a positive coupling between upwelling and retention. clustered around 6 $m.s^{-1}$ (upper figure); this value corresponds to the average wind intensity of the OEW (lower figure).

- A second cell is located on the coastal side of the shelf-break. A convergence occurs in the nearshore area. In this cell, phytoplankton and other biological components tend to become trapped and retained along the coastal side of the shelf.

In an upwelling with a double-cell circulation structure, the coastal cell represents a very favourable environment for fish to reproduce: eggs and larvae are not spread in the offshore environment but can be retained in the productive and relatively stable coastal environment.

Fish reproductive behaviour and environmental changes

The way we consider group of biological entities and utilise them is a controversial subject in ecology, particularly when referring to relevant scales of observation. In ecology we consider demographic exchangeability (i.e., individuals have the same dynamics when they are confronted by any perturbation) but we know that every individual is different from another. Thus, according to Cury (1994), individuals tend, when they reproduce, to try to find in their surroundings the environmental conditions with which they were imprinted at an early stage. This hypothesis was developed using arguments developed within comparative ecology (Cury 1994) and its implications for fish population dynamics was investigated using an IBM (Individual Based Model) (Lepage and Cury 1997; McGlade 1999). This represents an ecology based on individual dynamics and consequently the impact of environmental changes can be explored using spatially explicit models (Lepage and Cury 1996). It is also possible to test the effect of long term and global climatic changes on fish population dynamics such as a slow increase in temperature over the years.

Discussion: the Right Scale for the Right Process, the Right Tool for the Right Process

Relatively few oceanographic data have been collected off West Africa, however these data have been collected over long time periods. Thus, the spatial structure of the environment has been poorly documented whereas the temporal aspects have been extensively addressed. The quality of these data appears to be adequate to explore patterns that relate fish population dynamics to the environment, as drastic changes have been observed at different scales (month, seasons, year, decades). The research done in West Africa over the past forty years stresses the importance of collecting environmental time series of relevant variables such as SST or wind but it is crucial, as spatial dynamics is now of prime importance in fisheries related problems, that particular attention be devoted to the collection of more oceanographic data through surveys related to well-defined related fishery or ecological questions.

Table 10- 2 presents some of the ecological processes that are addressed in this paper and tries to relate the scales at which each process could be studied. Scale of observations and scale of studies are sometimes disconnected in time and space and difficult to identify. Moreover time lags often exist between environmental processes and the response of the ecological process. There is thus a requirement for tools that allow us to deal with time and space. Usually, an ecological process responds in a non-linear fashion as threshold effects and discontinuities are observed when related to environmental factors (Cury and Roy 1991). Methods and tools are now available that address these features in ways that can help to

better understand the coupled dynamics between the environment and the ecological processes in the Canary Current and Guinea Current ecosystem.

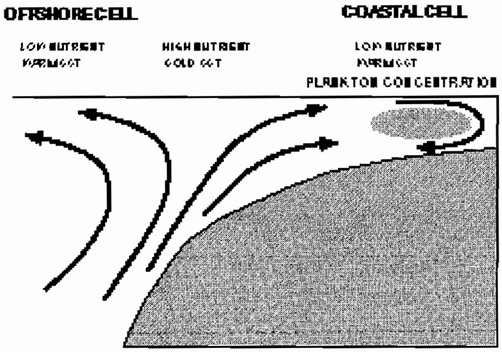


Figure 10-12 Sketch view of a double-cell vertical circulation structure in an upwelling located on a wide shelf, down-wind of a cape.

Ecological process	Scale of observation	Ecological data	Environmental data	Method	Results	Countries
Availability	fortnight	cpue	SST (coastal, COADS)	Multivariate time series analysis	Depend on enrichment process	Côte d'Ivoire
School size	fortnight, month	catch per set	SST (coastal, COADS)	regression	Depend on food availability	Senegal Côte d'Ivoire
Seasonal Migration	month	catch	CUI SST coastal and COADS	Comparative dynamics (CUI)	Depend on differential food production	Senegal Morocco
Changes in Migration	Month, annual	Catch	SST coastal, Satellite (Meteosat)	Spatial upwelling index	Depend on yearly strength of the upwelling	North-west Africa
Inter- annual abundance	annual	Catch cpue	SST, wind	Climprod (production models) GAM	Depend on availability/ Abundance OEW (optimal environmental window)	Côte d'Ivoire Senegal Morocco
Long term abundance	decadal	Catch cpue	SST (coastal, COADS)	GAM, STL (generalized additive models)	Change in the seasonal pattern and in the long term environment	Côte d'Ivoire
Retention area	decadal	Eggs and larvae	SST (COADS), satellite	Models (3D, IBM)	Double cell circulation	Morocco, Senegal,
Reproductive behavior	microscale	Individual fish dynamics in space	Global change	Comparative Evolutionary ecology, IBM	Ecology of individuals	

Table 10-2 Ecological processes and related scales of observation for the ecological and environmental data. Methods used and main results obtained in West-Africa.

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