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El Niño-like warm events in the Eastern Atlantic (6°N, 20°S) and fish availability from Congo to Angola (1964–1999)

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Abstract – Long term changes in catches of two sardinella species off equatorial West Africa seem inconsistent with their thermal preferences. *Sardinella maderensis* is usually fished during the warm season in low salinity waters, while *S. aurita* is associated with cold upwelled waters. However, in the Congo fisheries, *S. maderensis* dominated the catches from 1964 to 1983, when temperatures were moderate or cool; subsequently *S. aurita* became the most important from 1984 onward, as there was pronounced warming. The movement of water masses related to Atlantic Niño-like episodes explains this paradox. These warm events are associated with enhancement of the equatorial counter currents. When the eastward transport strengthens south of the equator (Benguela Niño), it drives an influx of warm water towards Angola, which repels *Sardinella aurita* northwards. Then, trapped near the coast by the subsuperficial warm water intrusion and the deviation of the Congo River plume, *S. aurita* becomes more concentrated and vulnerable to fishing. This is the most frequent situation during warm events. However, when the anomaly involves the north equatorial counter current (Guinea Niño), we assume that this surge of water in the Bight of Biafra leads to a water leakage toward the south, along the Gabon coast. This warm and low salinity water tongue, homologous to the Peruvian El Niño current, would drive *Sardinella maderensis* towards the Congo fisheries, but would force *Sardinella aurita* offshore making it less accessible to the fisheries. This situation is likely to have occurred in 1987–1988 when there were large catches of several species linked to brackish waters (bongas, *Pseudotolithus*, soles, catfish, sharks and spiny lobsters). On the contrary, decadal variations of catches of the two species are consistent with regime shifts of the Congo River: *Sardinella maderensis* is dominant when the outflow is above average (1960s and 1970s) and is replaced by *Sardinella aurita* when the runoff is weak (1980s and 1990s). In Angola, the catches of horse mackerel shift southwards during the warm years preceding 1976, then northwards during a cool period ending in 1983. From 1984, the abundance of horse mackerels over the shelf increases after warm events. © 2001 Ifremer/CNRS/Inra/IRD/Cemagref/Éditions scientifiques et médicales Elsevier SAS

warm events / Atlantic El Niño / coastal pelagic fisheries / clupeids / sardinella / tropical Atlantic Ocean / Western Africa

Résumé – Événements chauds de type « El Niño » dans l'Atlantique oriental (6°N, 20°S) et impact sur les pêches du Congo à l'Angola (1964–1999). Les changements à long terme des captures respectives des deux espèces de sardinelles en Afrique équatoriale vont à l'encontre de ce que l'on peut attendre de leurs préférences thermiques. *Sardinella maderensis* vit dans les eaux chaudes et peu salées tandis que *S. aurita* est inféodée aux eaux froides des upwellings. Cependant, au Congo, *S. maderensis* domine les captures de 1964 à 1983, période où les températures sont moyennes ou froides et *S. aurita* devient plus importante à partir de 1984, alors que le réchauffement est prononcé. Les déplacements de masses d'eaux consécutifs aux épisodes de type « Niño atlantique » pourraient expliquer ce paradoxe. Ces événements chauds sont liés à une intensification des contre courants équatoriaux. Lorsque le renforcement des courants vers l'est se produit au sud de l'équateur (Niño benguéléen) il entraîne une intrusion d'eau chaude devant l'Angola, qui rejette *Sardinella aurita* vers le nord. Bloquée à la côte par l'afflux d'eaux chaudes subsuperficielles et la déviation du panache du fleuve Congo, *S. aurita* devient alors plus vulnérable. C'est la situation la plus fréquente lors d'événements chauds. Cependant, lorsque l'anomalie concerne le contre courant nord équatorial et le courant de Guinée (Niño guinéen), nous faisons l'hypothèse que cet afflux d'eau dans la Baie de Biafra entraîne un écoulement vers le sud des eaux guinéennes, le long de la côte gabonaise. Cette langue d'eaux chaudes et dessalées, homologue du courant péruvien El Niño, entraînerait *Sardinella maderensis* vers les pêcheries du Congo, mais rejetterait *Sardinella aurita* au large en la rendant moins accessible. Cette situation se serait notamment produite en 1987–1988 où diverses espèces liées aux eaux saumâtres (ethmaloses, *Pseudotolithus,* soles, silures, requins et langoustes) sont pêchées en grand nombre. En revanche, les variations décennales des

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captures des deux espèces sont cohérentes avec les changements de régime du fleuve Congo : *Sardinella maderensis* domine, alors que les écoulements sont supérieurs à la moyenne (décennies 1960 et 1970), puis elle est remplacée par *Sardinella aurita* lorsque les débits sont plus faibles (décennies 1980 et 1990). En Angola, les captures de chinchard se déplacent vers le sud pendant les années chaudes précédant 1976, puis vers le nord lors d'une période froide se terminant en 1983. Depuis 1984, l'abondance des chinchards sur le plateau continental augmente à la suite des événements chauds.

événements chauds / El Niño atlantique / pêches pélagiques côtières / clupéidés / sardinelles / Océan tropical Atlantique / Afrique de l'Ouest

1. INTRODUCTION

The El Niño Southern Oscillation (ENSO) of the Pacific Ocean has counterparts in other oceans. Warm anomalies, similar to El Niño events, have been recorded by Merle (1980), Hisard (1980, 1988), Hisard et al. (1986) and Shannon et al. (1986) in the tropical Atlantic. The connection between Pacific and Atlantic Walker atmospheric convection cells has been suggested as an explanation of the out-of-phase coupling of the Pacific ENSO and Atlantic Niños/Niñas alternance (Philander, 1990). During a Pacific El Niño, a wide expansion of the zone of rising air over northern South America strengthens easterly winds over the Atlantic, while the reverse occurs during the opposite phase (La Niña): sinking air over the American continent weakens the trade winds and can reverse them to westerly winds. Changes in the wind stress induce changes in the thermocline depth, zonal currents and distribution of warm water masses. During the Atlantic warm phase (an Atlantic El Niño), internal long waves and strengthened eastward currents, triggered by the relaxation of the easterly trade winds, tend to accumulate warm water masses on the African side of the Atlantic. During these warm events, very high rainfalls occur on the northern coasts of the Gulf of Guinea and on the usually arid Angolan and Namibian coasts, and the cold waters of coastal upwelling regions are overlaid by warm waters with low salinity. An 'Atlantic Niño' can include a 'Benguela Niño' (Shannon et al., 1986, Gammelsrød et al., 1998) and/or a warm event spanning only the northern Gulf of Guinea, termed a 'Guinea Niño' (Hisard, 1980; Merle, 1980).

Since the mid-1970s, El Niño events have increased in strength and frequency. Negative anomalies of the southern oscillation index were twice more frequent since 1976 than during the preceding 25 years (Voituriez and Jacques, 1999); and the largest two Niños of the century (1982–83 and 1997–98) were also observed during the last two decades. The severe drought that has struck the Sahel and less severely equatorial Africa since the 1970s is a possible consequence of this long negative phase of the southern oscillation (Mahé and Olivry, 1995, 1999).

Likely consequences of warm events for African coastal fisheries have become more evident since the mid 1970s. Off Ghana and the Ivory Coast, a dramatic increase in the *Sardinella aurita* stock has coincided with the increased frequency of Niños events. The intensification of the zonal transports, due to repeated Atlantic Niños, widens the coastal eddies in the Guinea Current and could explain the burst of sardinellas (Binet, 1997). Their spawning areas are situated in coastal zones where eddies increase the nutrient renewal and help inshore retention of fish larvae. South of the equator, the influence of Benguela Niños on fish distribution and abundance has also been observed in Angola and Namibia (Shannon et al., 1988; Luyeye, 1995; Gammelsrød et al., 1998).

Off Angola, large stocks of sardinellas *Sardinella maderensis* and *S. aurita*, sardine *Sardinops ocellata*, Cunene horse mackerel *Trachurus trecae* and Cape horse mackerel *Trachurus trachurus capensis* fuelled considerable pelagic fisheries. More than 500 000 t were landed by purse seiners in 1972 (De Campos Rosado, 1974), but this industry collapsed in 1975 after the independence and the departure of the Portuguese fleet. Large purse seiners from the Soviet Union replaced the former vessels and landed about 300 000 t annually from 1979 to 1989. At the same time, the catch of the national fleet was near 50 000 to 80 000 t (Luyeye, 1995). Since 1992 the total catch has been less than 100 000 t (FAO, 2000). According to the surveys performed by the R/V *Dr Fridtjoft Nansen* from 1985 to 1996, *Sardinella maderensis* was the dominant species off Angola, in contrast to the commonly observed situation in past decades when *Sardinella aurita* dominated the catches (FAO, 2000).

The two sardinellas constitute also the bulk of the Gabon and Congo fisheries, which remain moderate in comparison to those of Angola. The Congo pelagic fisheries, which operates from Pointe-Noire, grew from 6 000 t in 1978 to 15 000 t five years later, and similar quantities were landed in Gabon (FAO, 1999). In Congo, *Sardinella maderensis* dominated the catches up to 1983, after which *S. aurita* became the predominant species. Thus it seems that pelagic fish populations experienced opposite changes off Congo and Angola.

Sardinella maderensis is a sedentary species inhabiting coastal, warm and often brackish waters, while *Sardinella aurita* prefers upwelling areas and can migrate to avoid unfavourable environmental conditions. During the main warm season, from February to April, *S. aurita* dwells near the bottom about the shelf break and it rises to the surface and near the coast

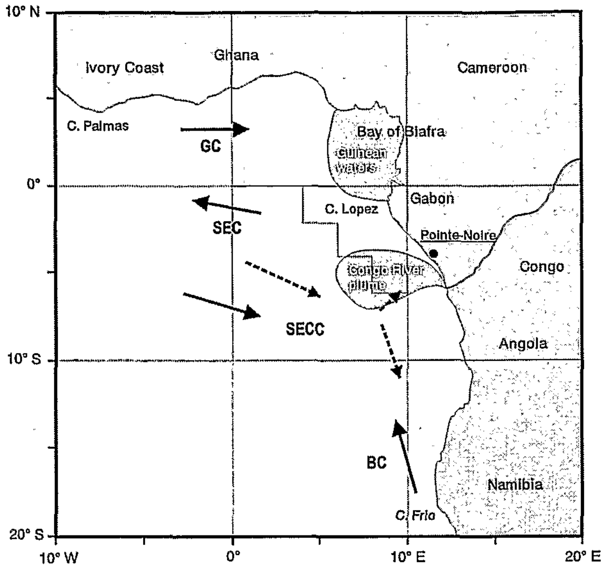

Figure 1. Map of the Gulf of Guinea and Southeast Atlantic Ocean indicating the three areas (light shadow) from which the sea surface temperatures are averaged: 'Guinea' (0°–6°N, 0°–10°E), 'Gabon–Angola' (0°–10°S) and 'Benguela' (10°–20°S). Dark shadowed areas: fresh water pools of Guinean water and the Congo River plume. GC: Guinea current, SEC: south equatorial current, SECC: south equatorial counter current in normal years (full line) and during warm events (broken line), BC: Benguela current.

during the major cold seasons, from June to September (Boely and Fréon, 1979; Ghéno and Fontana, 1981). *Sardinella* is a tropical plankton feeder and *Sardinops* a temperate one. The trachurids feed on larger food items higher in the food chain, and they are mostly found at the periphery of high primary production areas, not in the core of upwelling regions.

The two largest pools of low salinity waters in the eastern tropical Atlantic are the Bight of Biafra (Guinean waters) and the Congo River plume (*figure 1*), (Berrit, 1966; Wauthy, 1977; Dessier and Donguy, 1994). Heavy rains that occur during Atlantic Niños increase the discharge of continental fresh water and swell these pools. We suggest that the strengthening of the eastward flowing north and/or south equatorial counter currents (NECC and SECC), lead to a southwards discharge of Guinean waters and/or deviates northwards the runoff of the Congo River. A rearrangement of fish species distributions follows, according to their ecological preferences.

When a Benguela Niño occurs, the arrival of an oceanic warm water mass on the Angolan shelf is likely to push northward the Congo River outflow. In turn, it is likely that fish less tolerant to warm and low saline waters (*Sardinella aurita*) would be driven northward and trapped against the coast by the Congo River plume, where they are available in great numbers to canoe fishermen, in spite of the high sea surface temperature (*SST*) anomalies. However, when the warm event rather concerns the Gulf of Guinea, we suggest that the freshwater pool of the Bight of Biafra flows towards the south. This would drive more brackish species, such as *Sardinella maderensis*, into the nets of Congolese artisanal fishermen, and drives offshore the species that favour cool and saline waters.

This paper investigates interannual changes in the coastal fisheries, especially the pelagic fisheries from Gabon to Angola, and presents these changes within the context of warm events. Particular attention will be paid to examining how warm events may alter the availability of particular species according to their effect on local water masses and river plumes. Off Congo, we will see that the fish distribution is differently affected by the warm episodes from the Gulf of Guinea or from the northern Benguela. Surface observations from ships-of-opportunity and coastal temperatures from Pointe-Noire (4°S) are analysed to determine years of warm events occurring from the Gulf of Guinea to northern Namibia (6°N, 20°S). Fishery statistics from Pointe-Noire (Congo) are examined to follow the changes in the availability – not the recruitment – of the two sardinellas and some other species to coastal fishery during warm events.

2. DATA SERIES

2.1. Oceanographic and climatic data

The sea surface temperatures (*SST*) from the network of ships-of-opportunity operating in the tropical Atlantic, are regularly updated in a data base at the IRD centre in Brest (J. Servain, unpublished data). The raw data are averaged in order to obtain monthly values in 5° longitude by 2° latitude quadrangles; then, using an objective analysis method, a 2° × 2° gridded monthly data base is created (Servain and Lukas, 1990). For the purpose of this study, *SST* from the three boxes entitled: 'Guinea'(0°–6°N, 0°–10°E), 'Gabon–Angola' (0°–10°S) and 'Benguela' (10°–20°S) were averaged monthly, then annually (*figures 1, 2,* and *3*). The Gabon–Angola data set includes eleven 2°× 2° squares in the following quadrangles: 0–2°S × 4–10°E, 2–4°S × 6–10°E, 4–6°S × 8–12°E, 6–10°S × 10–14°E. The Benguela data set includes nine squares: 10–20°S, 10–14°E.

The sea surface temperatures and salinities at Pointe-Noire are also averaged monthly from daily observations by the Orstom centre of Pointe-Noire (Makaya et al., 1991–1994; Locko, 1998), in the harbour (*1961–1976* and *1983–1999*) and at the extremity of a 1600 m-long wharf (1976–1982). Overlapping observations between the harbour and the wharf, for half of 1976, allow one composite series to be formed from the two data sets (*figures 2* and *3*).

The annual mean curves were fitted with cubic polynomial regressions and occurrences of warm events are defined as annual *SST* equal or superior to 0.5 standard anomalies (*figure 3*).

Congo River outflows, recorded at Brazzaville (*figure 4*), are obtained from the *Observatoire hy-*

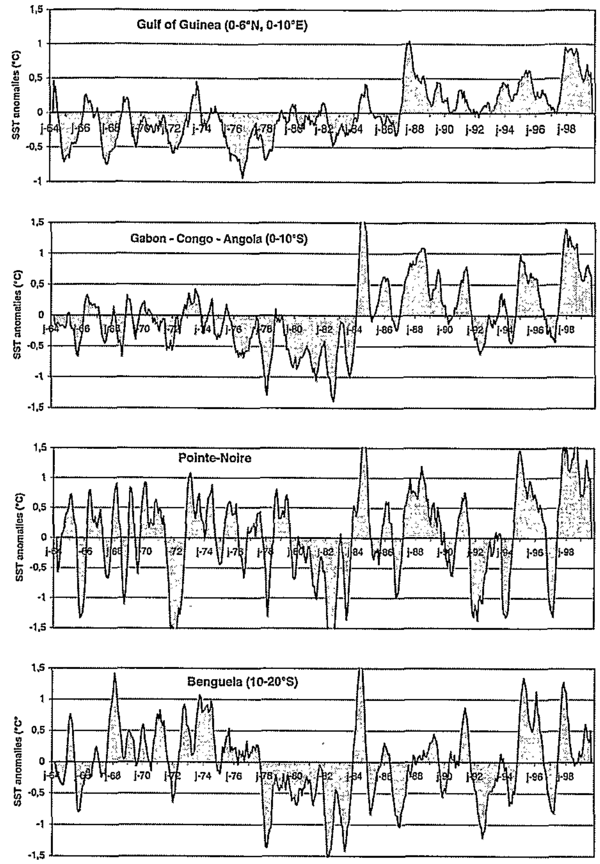

Figure 2. Sea surface temperature anomalies (1964–1999) 7 months moving averages, from the Guinea Gulf, Gabon–Angola and Benguela boxes, and from Pointe-Noire (4°50'S). See text and *figure 1* for the longitude range of the boxes. The tips on abscissa scale correspond to the first January.

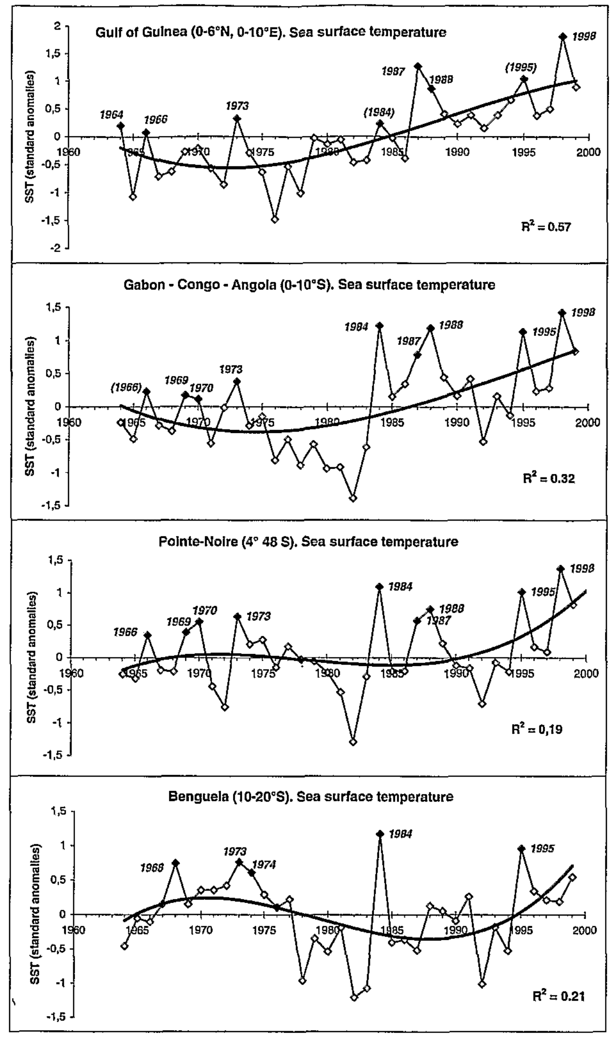

Figure 3. Sea surface temperature standard anomalies, annual means, from Guinea Gulf, Gabon–Angola, Benguela boxes and from Pointe-Noire (4°50'S). Interdecadal trends are fitted by cubic polynomial regressions, R^2 = coefficient of determination. Warm events are indicated by black marks.

drologique régional de l'Afrique de l'Ouest et Centrale (IRD, Ouagadougou, Burkina-Faso). The Congo has a double flood regime with two maxima in December and May, so the monthly standard anomalies, averaged for 'hydrological years' from August (y) through July ($y + 1$) are reported for each year (y). The rainfalls at Pointe-Noire airport (data from ASECNA) are reported as annual sums of monthly anomalies from the 1960–1990 climatology (*figure 4*).

2.2. Congo fisheries statistics

A small industrial fishery operates from the harbour of Pointe-Noire with some purse seiners (1 boat in 1964, 7 in 1990, 5 in 1996), the power of which varies between 150 and 390 kW. Most of these boats are second-hand units, which may be out of order several months at a time for repair work. Hence, although fishing occurs throughout the year, month-to-month variability in fishing effort does not strictly depend on the fish availability. The specific composition and fishing effort (estimated in operating days) were estimated from 1964 to 1984 (Ghéno and Fontana, 1981; M'Fina, 1985); since 1984, the Fishery Office statistics only indicate the number of boats and total landings (*figures 5* and *6*).

Unlike the industrial fishery, which has declined during recent years, a small-scale artisanal fishery has experienced considerable development and is landing, at the present time, more sardinellas than the purse-seiners. The artisanal fishing boats are large canoes owned and operated by Popos (Beninese). They use surface drift nets or bottom set-nets. The Popos immigrant fishermen started this fishery in 1967, with the motorization of the first large Ghanaian canoe (Gobert, 1983; Jul Larsen, 1994). Ten years later, more than one hundred canoes were fishing, and three hundred were numbered in 1999 (*figures 5* and *6*). The Congolese

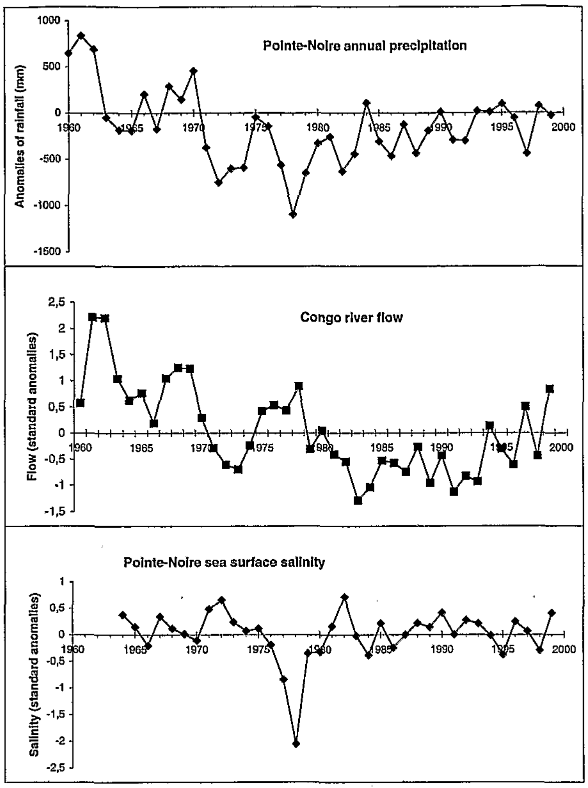

Figure 4. Rainfall at the Pointe-Noire airport, annual anomalies in millimetres (ASECNA). Outflow of the Congo River at Brazzaville (standard anomalies), from the '*Observatoire hydrologique régional de l'Afrique de l'ouest et centrale*' (Ouagadougou, Burkina Faso). Mean annual sea surface salinities standard anomalies at Pointe-Noire.

fishermen (Vilis) use smaller dug-out canoes. They catch essentially demersal fish with lines, set-nets, beach seines and other gears (*figure 7*).

Fishing effort and landings of the artisanal pelagic fishery has been monitored since 1981 (Gobert, 1985a, b; Orstom, 1986, 1987, 1988, 1991, 1994; Maloueki, 1996). The catches of the two sardinella species are recorded separately (*figure 6*). When sardinellas are very abundant, the restricted loading capacity of the canoes limits their maximum catch, which is not the case for purse-seiners (Gobert, 1985a); but the industrial fishery has to limit its landings to avoid saturation of the market, while the Popos can continue fishing because they control a wide web of fish processing (Jul Larsen, 1994). Industrial and small-scale fisheries compete for the same resource – although purse-seiners operate farther offshore – but the flexibility of the small scale fisheries allows the Beninese to dominate the pelagic fish market (Jul Larsen, 1994).

Gobert (1985b) found the average catch per unit effort (*cpue*) of the industrial and small-scale fisheries to be good indices of fish abundance. Because the range of operation of canoes is limited to about 50 km, fishermen have no alternative strategy in the choice of

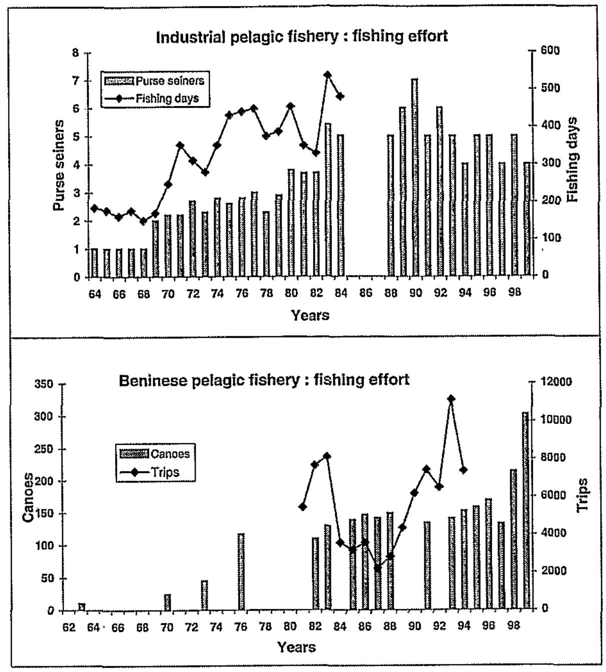

Figure 5. Fishing efforts of the Congo fisheries, from Pointe-Noire, 1964–1999. Industrial fishery: operating days and number of purse-seiners. Artisanal Beninese fishery, number of trips and number of Beninese fishing canoes.

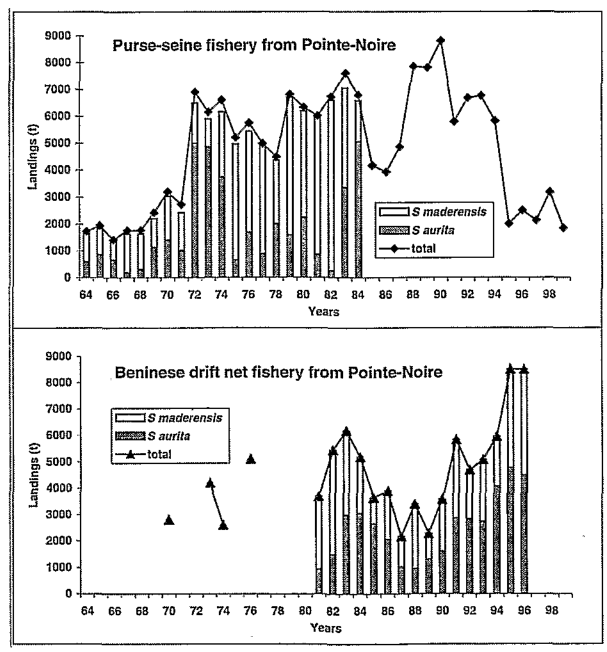

Figure 6. Landings of the Congo pelagic fisheries for *Sardinella aurita* and *S. maderensis* (in tons), at Pointe-Noire, 1964–1999. Industrial purse-seine fisheries and Beninese artisanal fishery.

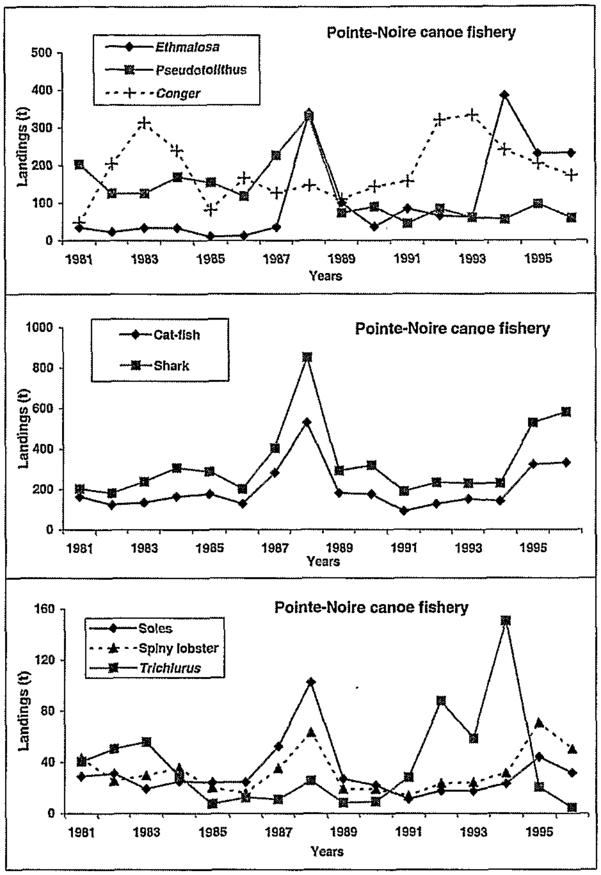

Figure 7. Recorded landings for some species caught by the Congolese small scale fishery (canoes), lines and set nets, at Pointe-Noire, 1981–1996.

fishing areas. The number of trips using surface gill nets is reported as the Beninese fishing effort from 1981 to 1994 (*figure 5*). It might be somewhat biased by a progressive increase in the average size of the canoes, which measured 9.3 m in 1973, 11.3 in 1981, and 12.2 in 1995, allowing a lengthening of the loaded nets. The nets were 500–700 m in length in 1983 and 900–1 200 m in 1992 (Jul Larsen, 1994). An increase in the net height is another possible bias. Their vertical range was usually 200 meshes, but in 1991 fishermen observed that doubling the height of the net (i.e. 400 meshes) allows a lengthening of the fishing season; indeed *Sardinella aurita* leaves the surface layer after the upwelling season. Nevertheless after 1992, the number of 400 mesh nets decreased. Purse-seiners can fish farther than canoes, but during the late 1960s and the 1970s they could not operate beyond the border of Cabinda, due to political troubles. At present, the cost of transit journeys and the problem of fish conservation limit their trips to northern Angola.

3. RESULTS

3.1. Climatic trends and Atlantic Niños

The long-term trends, extracted by the polynomial regressions, indicate an appreciable warming in all the series (*figure 3*). Three decadal periods, approximately up to 1973, 1974–1983 and after 1984 can be identified by their temperatures: around the mean, colder and warmer than average respectively. Another noticeable feature south of the equator is the progressive building up of the negative temperature anomalies preceding the sudden warming of 1984. This interdecadal mode of variability indicates some kind of regime shift occurring in the mid-1970s and around 1983. The interannual warm events mode is superimposed on this long-term variability. Here, we defined warm events as years when the *SST* equals or exceeds half the standard deviation from the fitted trends.

Pointe-Noire and the Gabon–Angola box display warm events in: 1966, 1969–1970, 1973, 1984, 1987–1988, 1995 and 1998. During the moderate events of the 1960s and 1970s, most of the warm anomalies occurred during the warm season (boreal winter), while during the 1984, 1987–1988, 1995 and 1998 largest events, warm anomalies lasted all year round (*figure 2* and *table I*). The Guinea box shows approximately the same events, while in the Benguela box, only four outstanding warm events (1968, 1973, 1984 and 1995) are recorded. Note that the variability off southern Angola is best represented than the northern Namibia.

Warm events recorded in the Gabon–Angola box and in Pointe-Noire were also observed in the Guinea and/or Benguela boxes, (except 1969–1970). This means that the Congo area is affected by conditions associated with positive temperature anomalies to the north and/or south, in other words, from Guinea or Benguela Niños. Three warm events (1966, 1987–1988, 1998), observed from the Gulf of Guinea to the Congo, were not identified in northern Benguela.

The 1968 warm anomaly observed from Ghana to Ivory Coast – failure of the major upwelling (June to September), heavy rains on the northern coast of the Gulf of Guinea (Hisard, 1980) – is identified in the Benguela box, but not in the Gabon–Angola records. The *SST* anomalies were in the eastern and mainly in the central ocean, centred around the equator (Huang and Shukla, 1997), and 1968 was not especially warm in Namibia (Shannon et al., 1986), while a slight warming appears in 1969–1970 from the Guinea and Gabon–Angola boxes, as at the Pointe-Noire coastal station.

The most conspicuous differences between the series occur during the last two decades. The 1984 event appears to be weak in the Guinea box. In fact, it was one of the largest warm episodes of the last four decades, but the main *SST* anomalies were in the southeast coastal regions (Huang and Shukla, 1997).

Table I. Atlantic Niños or warm events, from 1963 onwards.

Warm year	Event		Months with warm anomaly at Pointe-Noire												References
	Guinea Niño	Benguela Niño													
1963–1964	minor	major	?												(1, 2, 3, 4, 5, 6)
1966	minor					A	M		J				N	D	(5, 7)
1968	minor	minor	J		M	A									(1, 2, 5, 7)
1969–1970	minor		J	F	M	A									(7)
						A				A	S			D	
1973–1974	minor	minor	J	F				J							(1, 3, 4, 5, 7)
						A	M								
1981	minor														(5)
1984	minor	major					M	J	J	A	S	O			(1, 3, 4, 5, 6, 7)
1987–1988	major							J	J	A	S				(5, 7)
					M			J	J	A					
1995	major	major	J	F	·M			J		A		O	N		(6, 7)
1998	major	minor	J		M			J	J	A	S	O	N		(7)

The seasonal occurrence of warm anomalies is given for the months when *SST* was ≥ 1°C above the mean at Pointe-Noire. The numbers in brackets refer to the following references: (1) Hisard, 1980 and Hisard et al., 1986, (2) Merle, 1980, (3) Shannon et al., 1986, (4) Walker, 1987, (5) Carton and Huang, 1994, (6) Gammelsrød et al., 1998, (7) present study.

The years 1987 and 1988 were warm everywhere except in the Benguela box. Thus it is clear that warm events do not affect equally coastal and open sea areas, north and south of the equator.

Annual precipitation in Pointe-Noire seems to parallel the Congo River flow, at a first approximation (*figure 4*): high waters and abundant rains in the 1960s, low waters and poor rains in the early 1970s and 1980s, preceding a return towards the mean during the last decade. But a careful examination shows that the 1975–1980 period of excess outflow of the Congo River paradoxically corresponds to a rainfall minimum in Pointe-Noire. Further, the minimum sea surface salinity at Pointe-Noire occurred between 1977 and 1979, during a local precipitation minimum, corresponding to the return of floods in the Congo. Currently, the low Congo River flows during the last two decades appear to be coming to an end.

3.2. Coastal fishes

3.2.1. Sardinella fisheries

Industrial catch peaked in 1972–1974 (6490 t), 1982–1984 (7040 t), and 1988–1990 (8810 t) then fell to 2000 t in 1995 (*figure 6*). Then, the dramatic fall of industrial landings, after 1994, was not related to a change in the number of purse seiners. However, there is no indication of the real activity of these boats, possibly under-utilized due to political trouble and marketing difficulties. The catches of the small-scale fishery display two maxima, in 1982–1984 (6180 t) and in 1995–1996 (8910 t). Artisanal landings roughly parallel the fishing effort estimated in number of trips. Indeed, as previously mentioned, Beninese traders do not have difficulties selling off their catch, and as fishermen can adapt the fishing effort to the apparent fish abundance, the number of canoe trips is adjusted to the availability of fish.

From 1964 to 1984, (i.e. the first two decades) *Sardinella maderensis* was the most abundant species (60%) in the industrial catch (*figure 6*). From 1981 onwards (i.e. approximately during the last climatic period examined), *Sardinella aurita* slightly dominated the landings (51%) in the pelagic Beninese small scale fisheries. The main exceptions to this generalization are apparently related to warm events, i.e. during 1972–1974 and in 1983–1984 when *S. aurita* became the dominant species, and in 1987–1988 when the reverse happened as *S. maderensis* dominated catches.

This could mean that each fishery samples the sardinella species with different biases, due to their different gears and operating areas, purse-seiners generally working farther offshore and with deeper nets than artisanal canoes. But, a priori, this would conversely correspond to more *S. aurita* for the industrial fishery. In other respects, between 1981 and 1983 when the two time series overlap, the *Sardinella aurita*/*S. maderensis* ratio varies in the same way in both fisheries and again, from March 1997 to December 1999, the catch of one purse-seiner shows a strong dominance of *S. aurita* (72%) (personal communication of Mr Faucon, Socopec shipping). Thus, insofar as conclusions can be drawn from a 5 year overlap, it seems likely that these heavy changes in the apparent species ratio might not only be attributable to differences between fishing gears and areas. We think that

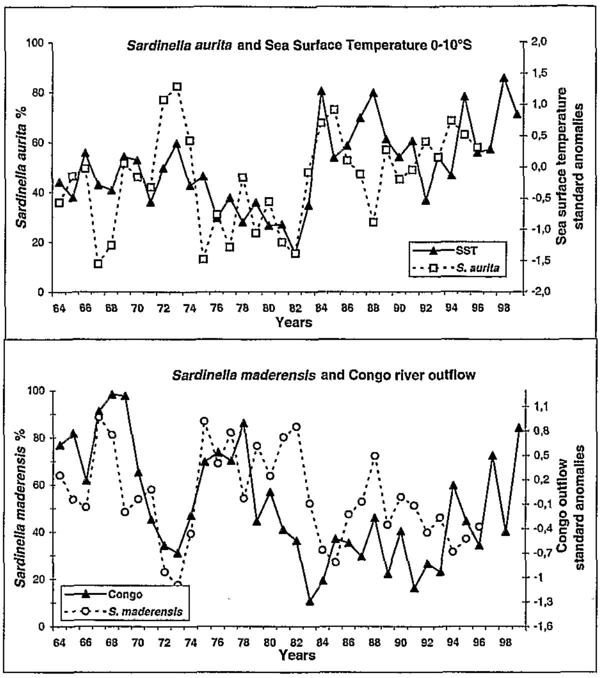

Figure 8. Composite series of *Sardinella aurita* (top) and *S. maderensis* (down) catches (%) in the purse-seiners (1964–1984) and Beninese canoes (1981–1996) fisheries, matched to the standardized anomalies of sea surface temperature from the Gabon–Angola area 0°–10°S (top) and of the Congo outflow (bottom).

the recorded catches of both fisheries reveal actual changes in the pelagic ecosystem.

However, the comparison of these results with the *SST* time series seems to contradict what could be expected. *Sardinella aurita* is considered to prefer seasonal upwelling areas, with reduced temperatures, while *Sardinella maderensis* lives in both upwelling and non-upwelling environments, in generally warmer, often brackish waters. However, the data of Pointe-Noire show the opposite (*figure 8*): *Sardinella maderensis* dominates up to 1983, during two decades of average and low *SST*s, while *Sardinella aurita* prevails from 1984 onwards (except in 1988), during 16 years of warm anomalies. Moreover, *Sardinella aurita* shows very significant catches during the warm events in 1973 and in 1984. And the relative abundance of the species in the landings increases also slightly in 1966 and 1969–1970, on the occasion of minor warm-events. This pattern seems to contradict the species ecology. The only clear exception, apparently consistent with the specific thermal preferences is 1987–1988, when high *Sardinella maderensis* catches coincided with two consecutive warm years. Then, with the exception of these two years, each warm event is marked by an augmentation of the *S. aurita* ratio.

Although the relationship between the species composition of sardinella and the sea temperature is different from what is expected, we find the normal relationship between this composition and the Congo River outflow: high ratios of *S. maderensis* generally correspond to heavy flooding of the Congo River (*figure 8*). When all years are included, the correlation between the proportion of *Sardinella aurita* and *SST* is 0.47 and between the proportion of *Sardinella maderensis* and the Congo outflow is 0.46 (33 d.f., $P < 0.01$).

3.2.2. Other species

The years 1987 and especially 1988 are also characterized, by very large landings of several other coastal fishes by the Congolese canoe fishery, using lines and bottom gill nets. Pelagic examples include bonga shads *Ethmalosa fimbriata*, and demersal examples include catfish (*Arius* sp.), soles, spiny lobsters, sharks and croakers *Pseudotolithus* (*figure 7*). *P. elongatus*, *P. typus* and *P. senegalensis* were trawled in the Congo and Kouilou estuaries, especially during periods of flooding (Fontana, 1981); all other species are also more or less linked to low salinity. The landings of shark, whose fishing has recently been boosted by the interest of Asiatic markets for their fins, increased strongly in 1987–1988 and in 1995–1996. Beninese fishermen of Pointe-Noire say that sharks follow the movement of frontal waters alternatively coming from Gabon or from the Congo River mouth.

In the Pointe-Noire fishery, the time series of the conger catches, mainly *Cynoponticus ferox* (Guinea pike conger), show an opposite pattern. These large fish, possibly exceeding 1.5 m in length, inhabit on the sea floor from 10 to 100 m depth and are mostly caught by trawlers during the cold season (Fontana, 1981). Canoe landings were high in 1982–1984 and 1992–1993, i.e. during periods of low outflows from the Congo River and very cold *SST* anomalies (*figures 5, 6*, and *9*). The congers probably follow the rise of isotherms and reach shallower waters during the coldest years.

4. DISCUSSION

The dynamics of near surface waters over the shelf from Gabon to Angola (*figure 1*) is driven by 1) a thin and superficial band of northward advection above a large southward countercurrent, 2) seasonal upwelling of deep equatorial under current waters, 3) the dilution of the Congo River plume towards the northwest, the west or even the southwest, 4) a possible – although debatable – southward extension of the low salinity waters from the Gulf of Guinea. Near Cape Frio, a thermal front separates these seasonally stratified waters from the more permanent upwelling off Namibia.

Coastal upwelling areas are associated with the northward surface circulation and additional energy of the southeasterly winds. Kelvin waves generated by the strengthening of easterly winds in the western tropical Atlantic and propagated up to the African coast along the equatorial waveguide probably also play a role in the seasonal lifting of the thermocline (Picaut, 1983). Any reversal of the coastal circulation,

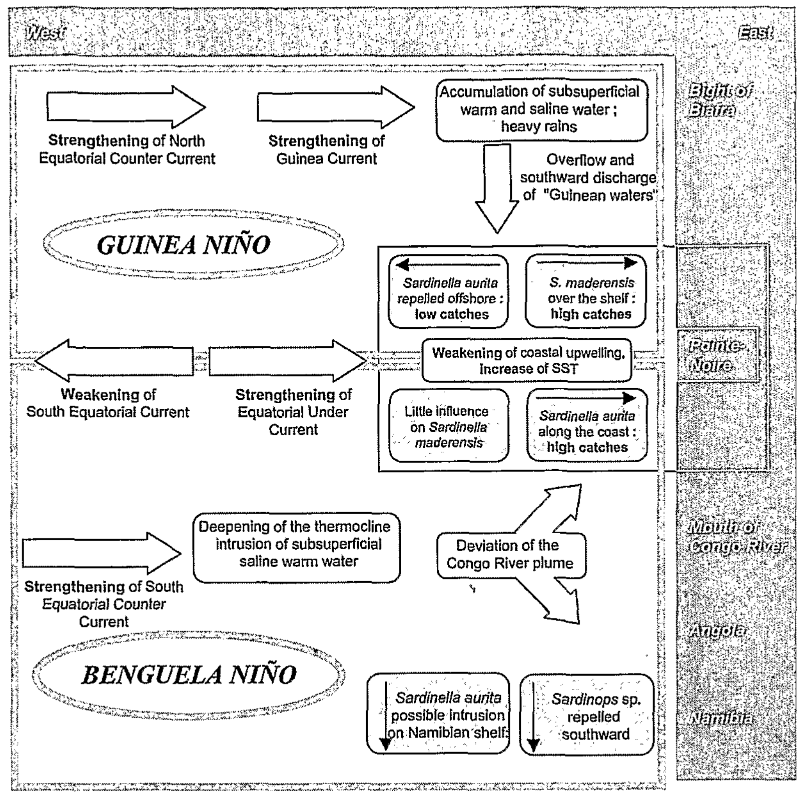

Figure 9. Diagram summing up the water masses deviations during warm events north or south of the equator (Guinea or Benguela Niño) and their consequences on the availability of clupeids *Sardinella aurita, S. maderensis* and *Sardinops* sp. to coastal fisheries. *SST*: sea surface temperature.

caused by an exceptional eastward development of the south equatorial counter current (SECC), corresponds to an inhibition of cold water upwelling, a retention of cold water lenses close to the coast of Congo and Angola (Gammelsrød et al., 1998), and an overlap of the cold waters of the Benguela by oceanic warm saline water of equatorial origin. These strong, unseasonal intrusions of warm and saline waters are the signatures of Benguela Niños (Shannon et al., 1986, Gammelsrød et al., 1998).

4.1. Atlantic Niño-like events

The intensification of trade winds over the western Atlantic during the warm phase of the southern oscillation, followed by an abrupt relaxation during its cool phase, generates Kelvin internal waves that propagate eastwards along the equator and deepen the thermocline in the eastern Atlantic. Therefore, during the ENSO cold phase of the Pacific Ocean, the Atlantic westward equatorial current and its associated upwelling are slowed down, while the return eastward circulation, north equatorial counter current–Guinea current (NECC–GC), equatorial under current (EUC) and south equatorial countercurrent (SECC) are strengthened. Offshore transport from coastal upwellings south of the equator is reduced or stopped and warm waters accumulate in the eastern tropical Atlantic (Hisard, 1980; Hisard et al., 1986; Katz et al., 1986), creating a warm event. So, Atlantic Niños (warm events) correspond to the cold phases of the Pacific (La Niña), i.e. periods of positive anomalies of the southern oscillation index (*SOI*). However, all warm events are not similar, and depend on the latitude of the main eastward return circulation and warm waters accumulation.

NECC and EUC were intensified during the warming of 1968 (Peterson and Stramme, 1991), i.e. during a cold phase of ENSO. In addition, Katz (1993) noted that from 1983 to 1989, there was a rough negative correlation between the flow of the eastward NECC and the *SOI*, with a variable time lag, meaning a strengthening of the NECC during Atlantic Niños. In simulating the 1987–1988 warm event, Carton and Huang (1994) obtained an eastward circulation along the equator and a strengthened NECC (therefore also likely a GC). Again, in November 1997, Signorini et al. (1999) reported an exceptionally strong NECC, at the beginning of the 1998 warm event. These events occur mainly north of the equator and can be named 'Guinea Niños'.

South of the equator, strong events occurred in 1934, 1963, 1984 (Shannon et al., 1986, 1988), and recently in 1995 (Gammelsrød et al., 1998). Weak Niño-like anomalies were also observed, in 1973–1974, in the Benguela *SST* (Walker, 1987). In 1984, south of the equator and up to 5°S, an unusual eastward current carrying warm water into the Gulf of Guinea was observed (Philander, 1986; Hisard et al. 1986). Simulations by Carton and Huang (1994), for

February 1984 and 1988, showed an eastward circulation along the equator and an anomalous southeastward south equatorial counter current (SECC), especially in 1984, reaching 10°E.

During such events, the SECC, broadened and intensified, drives warm and saline water towards the Angolan coast, flowing southwards over the Namibian shelf, overlying the Benguela upwelled waters (Shannon et al. 1986), and equatorwards (McLain et al., 1985) towards Congo. At the same time, the inter tropical convergence zone (ITCZ) moves abnormally to the south, and heavy rains flood the usually arid coast of Namibia. Shannon et al. (1986) termed these events 'Benguela Niños'.

Shannon et al., (1986) reported the presence of very saline waters on the Namibian shelf during such events, while off the Angolan coast, waters were abnormally warm and brackish (Gammelsrød et al., 1998). The warming, more pronounced off the shelf than near the coast (respectively 6°C and 1–2°C; at 30 m depth), reached 8°C at 30 m depth, and only 1°C at the surface. Thus, Gammelsrød et al. (1998) suggest that Benguela Niños are associated with a positive subsurface salinity anomaly in Namibian waters and a negative surface salinity anomaly in Angolan waters. Excess of local rains cannot account for the large volume of these low salinity waters, which seems related to the deviation of the Congo River plume, pushed back towards the coast by the warm oceanic waters.

According to the quoted literature, we can assume that Guinea and Benguela Niños are in fact two different scenarios of warm events depending on the latitude at which the eastward return circulation is mainly boosted during Atlantic Niños. If the eastward circulation anomaly mainly involves the SECC, influx of warm waters would hit the African shelf between the mouth of Congo and Cape Frio, invading the Angolan shelf and spreading southwards and equatorward. This is the best known scenario which seemed to be the most frequent. However, if the anomaly prevails in the northern hemisphere, the strengthening of the NECC–GC system would make the low salinity pool of Guinean waters overflow out of the Bight of Biafra, south of Cape Lopez.

Of course, there is place for intermediate situations. During the 1984 Atlantic Niño, unusual amounts of warm and saline waters accumulated in the Bight of Biafra, close to the 50 m depth, by anomalous eastward equatorial transport (Wacongne and Piton, 1992). However, the NECC (and the GC) were not enhanced (Carton and Huang, 1994). Thus, off Pointe-Noire, situated between the low salinity water pool of the Bight of Biafra and the Congo River outflow, the warm anomaly could originate from the north and/or from the south.

According to Berrit (1966), the low salinity waters found off Pointe-Noire originate from the Bay of Biafra, while Wauthy (1977) suggested they originate from dilution by freshwaters of the Congo River. Indeed, the mouth of the Congo is situated just 160 km south of Pointe-Noire and its plume, directed W or NW, can be detected 1000 km offshore (Piton, 1988). The ratio of waters coming from each origin probably depends on the respective importance of rainfalls over western and central Africa, and on changes in the eastern tropical Atlantic circulation. Freshwater yields in the Gulf of Guinea were high during the 1960s, decreased dramatically during the 1970s and reached a minimum in 1983 before returning in the late 1980s (Mahé and Olivry, 1999). Finally, it is worth noting that Berrit's paper (1966) on the prevalence of Guinean waters dates from the years of abundant rainfall in Sahelian countries, while Wauthy contests this hypothesis in 1977, ten years after the onset of the drought.

The years when warm events occur north of the equator, the ITCZ is stuck along the northern coast of the Gulf of Guinea, and enhanced precipitation increased the volume of the Guinean water low saline pool. The strengthened Guinea current, an unusual amount of equatorial under current saline water, and a deepening of the thermocline contribute to rising of the sea surface off the African coast, according to observations by Katz et al. (1986). This could account for the low saline waters of the Bight of Biafra flowing along the Gabon and Congo coasts. In the absence of offshore advection due to SEC interruption, this tongue of warm and low salinity water retained near the coast by Coriolis force, would run southwards, in a very similar manner to the Niño current in Peru. This scenario would be characteristic of a typical Guinea Niño.

4.2. Alternating dominance of clupeids

The seasonal distribution of the two sardinella species in landings at Pointe-Noire normally reflects their ecological preferences: *Sardinella maderensis* is caught in moderate numbers from October to May, that is during the warm season and during the flooding period of the Congo; while during the upwelling season, from June to September, the landings of pelagic fish are the highest and almost exclusively constituted by *Sardinella aurita*. The first species inhabits coastal waters of variable salinity, while the second migrates from the outer shelf where it lives under the thermocline during warm seasons, to coastal surface waters during upwelling seasons.

It is therefore quite normal that, in the Pointe-Noire fisheries, the relative inter-annual abundance of *Sardinella maderensis* be roughly related to the variations of fluvial discharge of the Congo River (*figure 8*). Up to the early 1980s, during high runoff years, *S. maderensis* was the dominant species. Subsequently, the situation reversed, the Congo River flow was low and *Sardinella aurita* abundance slightly exceeded the other species.

This contrasts with the situation off Angola, where *S. maderensis* dominated in the surveys of the R.V. *Dr Fridtjof Nansen* from 1985 to 1996, contrary to the preceding decades (FAO, 2000). However, the most striking paradox lies in the time series of landings off Congo. Increases in the *Sardinella aurita* catches at Pointe-Noire at the time of each warm event (*figure 8*) and more generally, higher percents of *S. aurita* after 1983, during the period of highest *SST*s and strongest warm events, seem to contradict the specific ecological preferences. Except in 1987–1988, when a clear minimum of *Sardinella aurita* occurs during very warm years, the quasi-regular increases in the catches of the more oceanic, upwelling dwelling species during the warmest years is surprising.

We suggest that the successive fluvial regimes of the Congo River and the two types of Atlantic Niños lead to different situations affecting the coastal fish availability and that could possibly be explained according to the following pattern.

During the cold decade of the 1970s, the core of the flourishing population of *Sardinella aurita* was in Angola. On the northern side of its habitat, in the frequently warm and brackish waters off Pointe-Noire, this species was subordinate to *Sardinella maderensis*. However, during the 1972–1974 Benguela Niño, we propose that the subsuperficial warm waters of the SECC confined the pelagic fish to the Angolan coast, deviated the Congo River plume equatorward, drove the less tolerant *S. aurita* northward and trapped them near the coast where they became highly available in the remaining cold, recently upwelled water lenses, pressed to the coast by the warm water intrusion (as above mentioned). Thus *S. aurita* became the most abundant pelagic species in the landings at Pointe-Noire. A similar restriction of its biotope led the Peruvian anchovy stock to collapse after the 1972 Niño: the stock was compressed inshore and further south by an advance of warm water that reduced the area with water temperature suitable for the anchovy shoals. This contributed to an increase in the catchability, which more than doubled. Although good *cpue* gave the impression that fish abundance was high, the stock was being rapidly depleted by fishing operations, while the recruitment was also sharply reduced (Csirke, 1988). In contrast, *S. maderensis*, tolerant of brackish and warm waters were not especially concentrated inshore.

The situation reversed for the last 15 years of the period examined. Increased temperatures and repeated warm events made the environment less favourable to *S. aurita* off Angola, where *S. maderensis* became the dominant species and vice versa off Congo. During the very strong 1984 Benguela Niño, the SECC was enhanced, but not the NECC; and at the peak of the drought, the freshwater input in the Bight of Biafra was at a minimum. Therefore, a similar scenario of northward migration and coastal trapping allowed *S. aurita* to dominate the Congolese catch for some years.

On the contrary, during the 1987–1988 warm event, warm anomalies were not reported south of 10°S (*figure 3*). Eastward current anomalies were limited to the north of 5°S. The NECC was strengthened during late 1987 and during 1988. Therefore the low salinity water pool of the Bight of Biafra, swollen by the return of precipitation north of equator (Mahé and Olivry, 1999), probably discharged southwards as a wedge of warm and brackish water inserted along the Congolese coast by Coriolis force, pushing *S. maderensis* and other low saline species from Gabon towards Congo, while *S. aurita* was forced offshore. In Pointe-Noire fisheries, *Sardinella maderensis* became dominant in the canoe landings, which remain moderate. Conversely, the 1988 catch of purse-seiners (the specific composition of which is unknown) was high, meaning that *Sardinella aurita* were probably offshore. In the Congolese fisheries, the Guinea Niño thus has opposed consequences on the distribution of the two sardinella species in comparison to the Benguela Niños.

The 1995 warm event, characterized by the presence of the largest warm anomalies south of the equator (*figure 3*) was predominantly a Benguela Niño (Gammelsrod et al., 1998), increasing the availability of *S. aurita*. In 1998, the high warm anomalies in the Guinea and Gabon–Angola boxes led us to suppose it was mainly a Guinea Niño, but we have few indications on the specific composition of the landings.

This pattern, based on four of the major warm events (1972–1974, 1984, 1987–1988, 1995) for which we have good fishery statistics, could be extended to minor events. It could explain most of the inter-annual variability in coastal pelagic fish availability. However, environmental changes may also cause fish recruitment to fluctuate. Given that warm events are usually preceded by cold ones, it is probable that strengthening of coastal upwelling during the Niña-like phase increases the planktonic production, attracts *Sardinella aurita* to coastal waters and improves their recruitment.

The fact that we observe higher percentages of *Sardinella aurita* in landings in 1964–1966, 1972–1974, 1983–1985 and 1994–1996 supports the idea that recruitment is enhanced during the cold year preceding the warm event and that availability remains high during the one or two following years. On the other hand, in 1978 in the middle of a cold period of *Sardinella maderensis* dominance, the percent of *S. aurita* in the landings increased suddenly. Indeed, exceptional floods of the Congo River were likely responsible for an unusual minimum of salinity at Pointe-Noire, during the upwelling season (*figures 4* and *8*); the plume of the river probably pushed *S. aurita* to the coast and increased its vulnerability.

During these Benguela Niños, *Sardinella aurita*, concentrated near the coast of Congo, are easily caught by the canoes; but they possibly become rare offshore, in the operating area of the purse-seiners. This may be one additional explanation of the drop of industrial landings in 1995–1996, compared to the good catches of the canoes (*figures 5* and *6*). This situation is somewhat comparable to the 1972 Ghana–Ivory Coast overfishing, when the drought made *S. aurita* abundant near the coast and highly available to the small scale fishery (Binet, 1982).

In southern Angolan waters, *Sardinops ocellata* and *Sardinella aurita*, respectively at the northern and southern limits of their area, are very sensitive to warm events. When a Benguela Niño arises, they are driven southward, towards Namibia, by the warm water influx. Increases in the Namibian sardine catch are reported during and after the 1968 and 1973–1974 warm events (Hewitson et al., 1989). In 1983, during an unusually strong intrusion of Angolan waters on the Namibian shelf, 1000 t of *S. aurita* were caught about 19°S, in an area where they were usually scarce (Thomas, 1984). Although warm anomalies were not reported by voluntary observation ships north of 20°S (*figures 2* and *3*), the 1982–1983 austral summer was anomalously warm in southern Benguela, south of 30°S (Shannon, 1983). The warm water intrusion mentioned by Thomas (1984) was probably too short and too coastal to have been observed by merchant ships. During the 1995 event, the Angolan fisheries of *Sardinella* sp. and *Sardinops* were severely depressed (Luyeye, 1995), and localized mortalities of *Sardinops ocellata* and other fish (*Trachurus trachurus capensis* and kob *Argyrosomus inodorus*) were observed. An abrupt decline in biomass was recorded in Angolan waters (*figure 10*), but the southward displacement of *Sardinops* increased its availability in Namibian waters (Gammelsrød et al., 1998).

4.3. Increase of trachurids catch

Horse mackerels (*Trachurus* sp.) are the dominant pelagic species in southern Angola, in the vicinity of the Angola–Benguela front (De Campos Rosado, 1974; Luyeye, 1995; FAO, 2000). They feed on larger food items than clupeids, therefore they usually dwell in waters advected off the periphery of upwellings, while sardines and sardinellas are found in coastal, recently upwelled waters. Water mass displacements related to climatic changes modify the area of these species, at inter decadal or inter annual time scales.

From the mid 1950s to the early 1970s, Crawford and Shannon (1988) report a southward shift in the distribution of catches of *Trachurus trecae*, followed by a return to the north (from the mid 1970s to 1984). The poleward movement corresponds, at least for the 1967–1975 period, to warm temperature anomalies, while the reverse, equatorward movement, occurs during the cold period, mid 1970s–1983 (*figures 2* and *3*).

After Benguela Niños, shoreward intrusions of warm waters increase the horse mackerel catchability on the Angolan shelf and repel them towards Gabon and Namibia. In 1964–1965, after the 1963 major Benguela Niño, the landings of *Trachurus* from the Angolan purse-seiners increased at the expense of sardinellas (De Campos Rosado, 1974). More recently, in 1985, 1989, 1995 and 1996, i.e. also after warm events, acoustic surveys of the R./V. *Dr Fridtjof Nansen* display high biomass of *Trachurus* (*figure 10*).

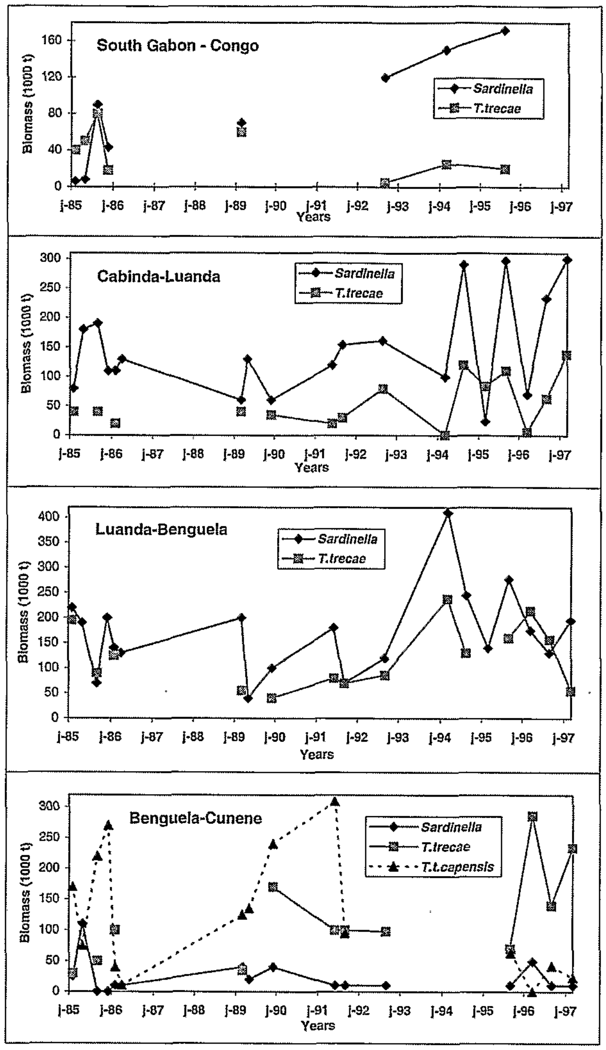

Figure 10. Pelagic fish biomass assessment from the R.V. *Dr Fridtjof Nansen* acoustic surveys carried out from 1985 to 1997, off Gabon to Angola (NORAD, 1994, 1995, 1996; FAO, 2000), from Gabon–Congo (0°30'–5°S), Cabinda–Luanda (5°–9°S), Luanda–Benguela (9°–12°30'S) and Benguela–Cunene (12°30'–17°S).

And in 1995, in spite of some mortalities caused by the warm event, the landings of *Trachurus trecae* and *T. trachurus capensis* increased strongly in the Angolan fisheries (Luyeye, 1995,Gammelsrød et al., 1998) .

All these events are probably linked to the shoreward displacements of ecological boundaries and correspond to replacement of the dominant pelagic fish stock by another (Silvert and Crawford, 1988). In the Namibian fishery, the end of the sardine period (mid 1970s) was followed by an increase in relative abundance of horse mackerel and anchovy (Crawford and Shannon, 1988). While we do not know if this results from a change in the target species or a real change in abundance, it is worth noting that the relative increase in *Trachurus* landings – about 10% in 1977, 30% in

1982–1983, and 50% in 1984, 1986 and 1988 – roughly parallels the warm event frequency. Similar increases or decreases of horse mackerel fisheries, in phase with warm or cold anomalies respectively, were observed in the Canary current (Binet, 1988; Binet et al., 1998), in the Humboldt current (Yanez, 1998), and off Tasmania (Harris et al., 1992; Young et al., 1993).

Ecosytem theory (Odum in Frontier and Pichod-Viale, 1991), points that in their early functioning stages, animal communities rely on vegetal production and can reach high biomass. As the system matures, other species with various feeding regimes settle and flourish; the total biomass decreases as biodiversity increases. The changes observed from the centre to the periphery of upwelling or before and after a warm event (decreases in the abundance of planktivorous clupeids, increases in the abundance of predatory horse-mackerels, accompanied by a collapse in the total yield) agree well with the theory concerning shifts from a young to a mature ecosystem.

5. CONCLUSION

The distribution and amount of upwelled and low salinity waters on the Congo and Angolan shelves are probably the main factors governing the respective abundance of the two sardinella species.

Changes in the flood regime of the Congo River is the first cause of variation at the decadal time scale. During the 1960s and 1970s, outflows exceeded the average and *Sardinella maderensis* was generally the predominant species in the landings. Then, the drought, which struck the Sahel for one decade, extended towards equatorial Africa and decreased the river flow; *Sardinella aurita* became slightly prevalent during the 1980s and 1990s in the Congolese fisheries. Currently, this situation seems to be reversing.

At the shorter time-scale of ENSO events, changes in the zonal oceanic currents modulate the dispersion of fluvial waters on the shelf. Since 1984, warm events became strong and frequent in the eastern part of tropical Atlantic. During these Niño-like episodes, momentary strengthening of eastward anomalies of the circulation accumulates warm water masses towards Africa. In most cases, the SECC, exceptionally prolonged, deviates these warm, saline waters towards Angola and Namibia. This is a Benguela Niño. When arriving off the Congo and Angolan shelves, these water masses drive back the Congo River plume against the coast, which either drives away fish intolerant to low salinities, or traps them close to the shore. *Sardinella aurita* can be fished in northern Namibia for a while and becomes highly available in Congo, especially to the canoe fishery. Conversely, *S. maderensis* becomes prevalent in Angola. During a Namibian sardine period the *Sardinops* catches could be boosted for some time by their migration from southern Angola. The yield of *Trachurus* is good in Angola, during and after the warm event.

However, if the strengthening of eastward current occurs mainly in the northern tropical Atlantic and involves the NECC–GC system, the warm event should be named 'Guinea Niño'. It seems likely that strengthening of the GC, combined with high fresh water supply to the Bight of Biafra, can lead to a southward overflow of Guinean low salinity waters. This leakage of low salinity waters, flowing along the edge of the Gabonese coast, causes coastal species tolerant to brackish waters, like *Sardinella maderensis*, bongas, soles, cat fish, croakers and even sharks, to be caught in great numbers by the craft boats, while fish less tolerant to brackish waters, like *S. aurita*, are repelled offshore and are caught in smaller numbers in the canoe fishery.

Atlantic warm events appear to lead to completely different situations for the Congolese fisheries, according to the latitude at which relaxation of the wind triggers the strengthening of eastward circulation. This study puts forward explanations in terms of fish availability. However, environmental changes may also cause fish recruitment to fluctuate. For example, decreases in primary production, which may be expected because upwelling is reduced during Benguela Niños, will probably lower the recruitment of *Sardinella aurita*, and the possible increase in available biomass of *Trachurus*, associated with these warm events, will not compensate for this loss.

Finally, Guinea and Benguela Ninos seem to boost *Sardinella aurita* fishing in Ghana and Ivory Coast and in Congo. Explanations are completely different in the two regions: broadening of coastal eddies enlarge habitat suitable for *S. aurita* in the Guinea current (Binet, 1997), while migration to avoid unfavourable waters concentrate the fish in restricted areas and increase their catchability in the Congo current. In the first case the stock is really enhanced, while, in the second case, it is just made more available. The stock is currently being underexploited (FAO, 2000), but if this situation had to change, attention should be given to avoid possible overfishing during warm events.

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References

Berrit, G.R., 1966. Les eaux dessalées du golfe de Guinée. Doc. scient. prov. 9. C.R.O, Abidjan.

Binet, D., 1982. Influence des variations climatiques sur la pêcherie des *Sardinella aurita* ivoiro–ghanéennes: relation sécheresse–surpêche. Oceanol. Acta 5, 443–452.

Binet, D., 1988. Rôle possible d'une intensification des alizés sur le changement de répartition des sardines et sardinelles le long de la côte ouest africaine. Aquat. Living Resour. 1, 115–132.

Binet, D., 1997. Climate and pelagic fisheries in the Canary and Guinea currents: the role of trade winds and southern oscillation. Oceanol. Acta 20, 177–190.

Binet, D., Samb, B., Taleb Sidi, M., Levenez, J.J., Servain, J., 1998. Sardines and other pelagic fisheries changes associated with trade wind increases in the Canary current upwelling (26°N–14°N), late 1960s–early 1990. In: Durand, M.-H., Mendelssohn, R., Cury, P., Roy, C., Pauly, D. (Eds.), Global versus local changes in upwelling systems. Coll. & Séminaires. Orstom, Paris, pp. 211–233.

Boely, T., Fréon, P., 1979. Les ressources pélagiques côtières. In: Troadec, J.P., Garcia, S. (Eds.), Les ressources halieutiques de l'Atlantique centre-est. 1ère partie: les ressources du golfe de Guinée de l'Angola à la Mauritanie. Doc. Tech. 186. FAO, Rome.

Carton, J.A., Huang, B., 1994. Warm events in the tropical Atlantic. J. Phys. Oceanogr. 24, 888–903.

Crawford, R.J.M., Shannon, L.V., 1988. Long term changes in the distribution of fish catches in the Benguela. In: Wyatt, T., Larrañeta, M.G. (Eds.), International symposium on the long term changes in marine fish populations. Vigo 1986, pp. 449–480.

Csirke, J., 1988. Small shoaling pelagic fish stock. In: Gulland, J.A. (Ed.), Fish population dynamics: the implications for management. John Wiley and Sons, Chichester, New York, Brisbane, Toronto, Singapore, pp. 271–302.

De Campos Rosado, J.M., 1974. A study of the statistics of the purse-seine fishery of Angola 1945–1972. Coll. Sci. Pap. Int. Comm. SE Atl. Fish. 1, 78–101.

Dessier, A., Donguy, J.R., 1994. The sea surface salinity in the tropical Atlantic between 10°S and 30°N – seasonal and interannual variations (1977–1989). Deep-Sea Res. 41, 81–100.

FAO, 1999. FAO yearbook fisheries statistics captures production 1997. FAO, Rome.

FAO, 2000. Report of the workshop on the small pelagic resources of Angola, Congo and Gabon. Luanda, Angola, 3–7 Nov. 1997. FAO Fish. Rep. 618, FIRM/SAFR/R618. FAO, Rome.

Fontana, A., 1981. Les stocks démersaux côtiers. Milieu marin et resources halieutiques de la République Populaire du Congo, Fontana, A. (Ed.). Trav. Doc. Orstom 138, 153–211.

Frontier, S., Pichod-Viale, D., 1991. Écosystèmes. Structures, fonctionnement, évolution. Collection Écologie 21. Masson, Paris.

Gammelsrød, T., Bartholomae, C.H., Boyer, D.C., Filipe, V.L.L., O'Toole, M.J., 1998. Intrusion of warm surface layer along the Angolan–Namibian coast in February–March: the 1995 Benguela Niño. S. Afr. J. Mar. Sci. 19, 41–56.

Ghéno, Y., Fontana, A., 1981. Les stocks de petits pélagiques côtiers. Les sardinelles. Milieu marin et ressources halieutiques de la République Populaire du Congo. In: Fontana, A. (Ed.). Trav. Doc. Orstom 138, 213–257.

Gobert, B., 1983. Quelques aspects socio-économiques de la pêcherie artisanale béninoise de Pointe-Noire (Congo). Rev. Trav. Inst. Pêches Marit. 47, 251–260.

Gobert, B., 1985. Stratégies et techniques de pêche des flottilles industrielles et artisanales: analyse des prises par unité d'effort des sardinelles au Congo, document scientifique n° 64. Orstom, Pointe-Noire, pp. 25–41.

Gobert, B., 1985. La pêche artisanale maritime au Congo. I Description et analyse des types d'exploitation, document scientifique n° 65. Orstom, Pointe-Noire.

Harris, G.P., Griffiths, F.B., Clementson, L.A., 1992. Climate and the fisheries off Tasmania. Interactions of physics, food chains and fish. S. Afr. J. Mar. Sci. 12, 585–597.

Hewitson, J.D., Melo, Y.C., Cooper, R.M., 1989. The Namibian pelagic fishing ressources during 1988. ICSEAF 16, 119–131.

Hisard, P., 1980. Observation de réponses de type « El Niño » dans l'Atlantique tropical oriental, Golfe de Guinée. Oceanol. Acta 3, 69–78.

Hisard, P., 1988. El Niño response of the tropical Atlantic during the1984 year. In: Wyatt, T., Larrañeta, M.G. (Eds.), International symposium on long term changes in marine fish populations. Vigo 1986, pp. 273–290.

Hisard, P., Hénin, C., Houghton, R., Piton, B., Rual, P., 1986. Oceanic conditions in the tropical Atlantic during 1983 and 1984. Nature 322, 243–245.

Huang, B., Shukla, J., 1997. Characteristics of the interannual and decadal variability in a general circulation model of the tropical Atlantic ocean. J. Phys. Oceanogr. 27, 1693–1711.

Jul Larsen, E., 1994. Pêcheurs migrants à Pointe-Noire. Continuité et changement perpétuel. DANIDA, Projet DIPA Rapp. Techn. 56, DIPA/WP/56. FAO, Cotonou.

Katz, E.J., 1993. An interannual study of the Atlantic north equatorial countercurrent. J. Phys. Oceanogr. 23, 116–123.

Katz, E.J., Hisard, P., Verstraete, J.M., Garzoli, S., 1986. Annual change of sea surface slope along the equator of the Atlantic Ocean in 1983 and 1984. Nature 322, 245–247.

Locko, A., 1998. Exploitation des données des stations côtières du Congo. Orstom, Brest.

Luyeye, N., 1995. Distribution and abundance of small pelagic fish off Angolan coast. ICES CM1995/H:32. ICES, Copenhagen.

McLain, D.R., Brainard, R.E., Norton, J.G., 1985. Anomalous warm events in eastern boundary current systems. CALCOFI Rep. 26, 51–64.

M'Fina, P., 1985. La pêche des sardinelles à Pointe-Noire de 1976 à 1984 document scientifique n° 64. Orstom, Pointe-Noire, pp. 1–24.

Mahé, G., Olivry, J.C., 1995. Variations des précipitations et des écoulements en Afrique de l'ouest et centrale de 1951 à 1989. Sécheresse 6, 109–117.

Mahé, G., Olivry, J.-C., 1999. Assessment of freshwater yields to the ocean along the intertropical coast of Africa (1951–1989) C.R. Acad. Sci. Paris, Sér. II, Earth Planet. Sci. 328, 621–626.

Makaya, J.F., Yoba, L.G., Locko, A., 1991–1994. Résultats des observations météorologiques et physico-chimiques effectuées au port (Pointe-Noire) à Matombi (baie de Loango) et au Centre Orstom (Pointe-Noire). En1988, 1989, 1990, 1991, 1992, 1993 documents scientifiques n° 640, 644, 650 S.R. Orstom, Pointe-Noire.

Maloueki, L., 1996. Statistiques de la pêche artisanale maritime au Congo1989–1992 document scientifique n° 77. Orstom, Pointe Noire.

Merle, J., 1980. Variabilité thermique annuelle et interannuelle de l'océan Atlantique équatorial est. L'hypothèse d'un « El Niño » Atlantique. Oceanol. Acta 3, 209–220.

NORAD, 1996. Campagnes sur les ressources halieutiques du Congo et du Gabon. Rapport des campagnes N.O. *Dr Fridtjof Nansen* 1994–1996. NORAD/FAO/PNUD, GLO/92/013.

Orstom, 1994. Statistiques de la pêche artisanale maritime au Congo 1984–1985 documents scientifiques n° 67, 68, 72, 73, 75. Orstom, Pointe-Noire.

Peterson, R.G., Stramme, L., 1991. Upper level circulation in the South Atlantic. Ocean. Progr. Oceanogr. 26, 1–73.

Philander, S.G., 1986. Unusual conditions in the tropical Atlantic Ocean in 1984. Nature 322, 236–238.

Philander, S.G., 1990. El Niño, La Niña and the Southern Oscillation. Academic Press, San Diego, CA.

Picaut, J., 1983. Propagation of the seasonal upwelling in the eastern equatorial Atlantic. J. Phys. Oceanogr. 13, 18–37.

Piton, B., 1988. Les courants sur le plateau continental devant Pointe-Noire (Congo), document scientifique n° 47. Orstom, Brest.

Servain, J., Lukas, S., 1990. Climatic atlas of the tropical Atlantic wind stress and sea surface temperature: 1985–1989. Ifremer, Brest.

Shannon, L.V., 1983. Preliminary report of the southern Benguela warm event,1982–1983. Trop. Ocean–Atmosphere Newsl. 22, 8–9.

Shannon, L.V., Boyd, A.J., Brundrit, G.B., Taunton-Clark, J., 1986. On the existence of an El Niño-type phenomenon in the Benguela system. J. Mar. Res. 44, 495–520.

Shannon, L.V., Crawford, R.J.M., Brundrit, G.B., Underhill, L.G., 1988. Responses of fish populations in the Benguela ecosystem to environmental change. J. Cons. Int. Explor. Mer 45, 5–12.

Silvert, W., Crawford, R.J.M., 1988. The periodic replacement of one fish stock by another. In: Wyatt, T., Lanañeta, M.G. (Eds.), International symposium on long term changes in marine fish populations. Vigo 1986, pp. 161–180.

Signorini, S.R., Murtugudde, R.G., McClain, C.R., Christian, J.R., Picaut, J., Busalacchi, A.J., 1999. Biological and physical signatures in the tropical and subtropical Atlantic. J. Geophys. Res. 104 C8, 18367–18382.

Thomas, R.M., 1984. Catches of *Sardinella aurita* off South West Africa in 1983. Int. Comm. SE Atl. Fish., Part II, Coll. Sci. Pap., 87–90.

Voituriez, B., Jacques, G., 1999. El Niño, réalité et fiction. COI Forum Océans. Unesco, Paris.

Wacongne, S., Piton, B., 1992. The near-surface circulation in the northeastern corner of the South Atlantic Ocean. Deep-Sea Res. 39, 1273–1298.

Walker, N.D., 1987. Interannual sea surface temperature variability and associated atmospheric forcing within the Benguela system. S. Afr. J. Mar. Sci. 5, 121–132.

Wauthy, B., 1977. Révision de la classification des eaux de surface du golfe de Guinée (Berrit, 1961). Cah. Orstom, Océanogr. 15, 279–295.

Yanez, R.E., 1998. Fluctuations des principaux stocks de poissons pélagiques exploités au Chili et leurs relations avec les variations de l'environnement. Thèse de doctorat. Université de Bretagne occidentale, Brest.

Young, J.W., Jordan, A.R., Bobbi, C., Johannes, R.E., Haskard, K., Pullen, G., 1993. Seasonal and interannual variability in krill (*Nyctiphanes australis*) stocks and their relationship to the fishery for jack mackerel (*Trachurus declivis*) off eastern Tasmania (Australia). Mar. Biol. 116, 9–18.