


1. INTRODUCTION

Geology and climate have shaped the regions along the West African coast where marine and inland waters meet to form estuaries, coastal lagoons and mangroves. The uniqueness of these paralic systems lies in their shallowness, their intense and variable gradients, the nature of the fluvial and marine sediment yields, and the mechanism by which the waters are confined or renewed. Silt from the land, both mineral and organic, passes through these environments before being carried towards the continental shelf, where it forms muddy bottom deposits.

These environments are particularly common along the West African coastline from the mouth of the Zaire River (6°S) to the Bissagos Islands (12°N) - an area which, with the exception of the stretch from Benin to Ghana and the Congo coast, receives at least 2 m of annual rainfall. Freshwater inputs to coastal waters also depend on watershed rainfall patterns.

The total area of paralic environments between Morocco and Zaire is 41 000 km², as compared with the 358 000 km² of the continental shelf. Coastal lagoons account for 5 000 km², estuaries for 11 000 km² (Kapetsky, 1981) and mangroves for 27 000 km² (John and Lawson, 1990). The biggest lagoon areas lie in Côte d'Ivoire and Gabon (more than 1 200 km² in each country), the biggest estuarine areas in Guinea-Bissau and Nigeria (2 400 km² in each country). The biggest mangroves are to be found at the foot of the mountain ranges with the highest rainfall, i.e., between Guinea-Bissau and Sierra Leone and between Nigeria and Cameroon. Off the Seed Coast, at the mouth of the Congo and in the Bight of Biafra, are brackish waters (<34‰) which Berrit (1966) calls "Guinean" waters.

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1 paralic, derived from the Greek para = beside and halos = salt, defines aquatic environments near the sea.
Throughout the world, coastal regions are the most heavily populated areas and Africa is no exception. The towns are often situated at the mouth of a river or the opening of a lagoon, which accounts for the damage already caused to the coastal systems by urbanization, industrialization and intensive farming. Finally, these environments are particularly sensitive to the current drought and their future thus gives even more cause for concern.

The zone where inland and marine waters meet is extremely productive. According to Kapetsky (1981), the coastal lagoons and estuaries of the CECAF region produce an average of 180 kg of fish/hm²/yr, or double the catch obtained in similar regions in other tropical, sub-tropical and warm temperate regions. However, the shrimp yield of 13 kg/hm²/yr is comparable to those in other regions of the world. There are comparatively more fishermen in the lagoons and estuaries of the CECAF region, but their individual output seems relatively low. In 1989, artisanal marine fisheries produced 800 000 t, of which 240 000 t probably came from the estuaries and lagoons, according to an extrapolation based on a yield of 150 kg/hm²/yr (Chaboud and Charles-Dominique, 1991).

This study, intended to show the role of freshwater in coastal ecosystems, will often show the reverse effect, in that recent climatic changes have reduced fluvial outflows, transforming estuarine ecosystems into marine and even hypersaline ones. These changes are often aggravated by recent human activities.

2. CLIMATIC AND HYDROLOGICAL REGIMES: RECENT DEVELOPMENTS

The amount of rainfall is regulated by shifts in the intertropical convergence zone (ITCZ). The moist southern trade winds move under the dry air of the northern trade winds and the shift of this system northwards during the southern winter brings the rainy season. The convergence arrives on the northern coast of the Gulf of Guinea in June and gives rise to heavy rainfall there, followed by coastal river flooding. The monsoon rains proceed towards the Sudanian zone until August, and while it is raining over the Sudanian-Sahelian region, there is a short dry season on the coast. When the monsoon shifts southward, the big rivers start to flood. Thus, in June along the northern side of the Gulf of Guinea, the outflow is mostly from the forested mountain ranges, then from September to November it is predominantly from the savanna in the north.

Rainfall is abundant nearly year-round near the Equator, although in Douala there is a maximum between June and August. Further south, along the Congo-Gabon coast, the rainfall pattern is determined by the extent to which maritime air penetrates over the land. There is a dry season from June to September during the southern winter. During the southern summer, the unstable monsoon flux produces rainfall maxima in November and in February-March. The rivers have two high-water seasons; the coastal rivers flood in May, the Zaire (Congo) in December. Beyond the zones influenced by the intertropical convergence but equatorward of the paths of the temperate depressions, stretch the desert regions.

Dry periods have been observed in West Africa since the beginning of the century, but they have never lasted as long as has the present one, extending since the late 1960s. At first this shortage of rain was attributed to the ITCZ being blocked over the coast of the Gulf of Guinea during its seasonal shift northwards. Another hypothesis is that the convergence zone migrated northwards too early and did not accumulate enough moisture during the winter at its southernmost position (Citeau et al., 1989).

The watersheds of the big Sudanian-Sahelian rivers have been greatly affected by the drought (Figure 1) and this has appreciably altered freshwater supplies to the coastal zones. But it is in the Casamance estuary that the most catastrophic changes have occurred.

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2 Coastal: environments situated on the boundaries between terrestrial and marine areas. The term has a more geomorphological meaning than paralic. Both terms apply to brackish waters, but sometimes also to highly saline waters.
3. OUTFLOW OF INLAND WATERS INTO THE SEA: HYDRODYNAMICS AND PRODUCTION

The process by which fresh and marine waters mix and the production that develops at this interface depend on the amount of river outflow and on the morphology of the river mouths, which determines the transit time of inland waters to the sea. The nature of the soluble load and solid particles transported by river waters depends on the type of plant cover on the watersheds.

3.1 Brackish estuaries

The estuary of the Sierra Leone River is subject to heavy scouring by tidal currents. Nevertheless, in the rainy season, and particularly during neap-tides, stratification is brought about by "estuarine" type circulation (Bainbridge, 1960): the flow of the freshwater towards the sea carries along by entrainment an admixture of salt water, which is replaced by coastal upwelling. This advective action may be quite strong, the river waters drawing along at their base a far greater volume of salt water than they discharge, depending on the length of the outlet. In a fjordal estuary in Madagascar, for example, Frontier (1978) states that the flow of upwelling water is 16 times that of the freshwater. The Zaire, despite a rapid and very high outflow (33,000 to 60,000 m³/s), also has an estuarine circulation: a canyon channel the seaward flow of the freshwater, allowing a plume of saline bottom water to travel as much as 40 km upstream from the mouth of the river (Eisma and van Bennekom, 1978).

The estuarine waters may stretch a long way from the coast. Off Guinea patches of water several metres deep with a salinity of 30% are found over bottoms of 30 m depth after the flood season. Off the Congo, dark-coloured waters with a salinity of 20% are frequently seen 100 miles from the estuary. But owing to the force of the flow and the narrowness of the outlet, the river water stays at intermediate salinities for only a fairly short time: the volume of freshwater in the outlet with a salinity of between 0 and 30% equals an outflow of two to three days as compared with 50 to 100 for the Colombia River (Eisma and van Bennekom, 1978). During the low-water period, upwelling develops along the coast and seems to draw the waters of the Congo, responsible for the general drop in surface salinity, out to sea. Along the northern side of their path these waters spread out in a plume over the ocean waters, while to the south they are separated from them by an almost vertical front. Off Pointe-Noire they flow more over the external part of the continental shelf, while the shore is often bathed by the outlets of the coastal rivers.

Each nutrient has its own dynamics. In the Sierra Leone estuary the turbid mixture created by the tide and the resuspension of river-borne organic waste produces higher phosphate contents in the estuary than upstream. Similarly, in the estuary of the Gambia, the content of reactive phosphate is highest in the lower part of the estuary. The floodwater phosphate content is half as high (Berry et al., 1985). Nitrates, on the other hand, are carried downstream in both the Sierra Leone and the Gambia. In the Gambia the nitrate content ranges from 7.7 to 54 micro g/l from the beginning to the end of the flood season. Silica is also carried down by the inland waters: the number of diatom frustules in the Sierra Leone estuary is indicative of silica abundance. Arid zone waters are richer in silica than forest zone waters.

Estuaries are usually highly productive places. However, phytoplankton can only develop when turbulence and turbidity diminish and there is sufficient mixture of fresh and seawater. The length of time the water remains at intermediate salinities greatly influences the ability of phytoplankton to take up the nutrient salts brought down by the rivers (Eisma and van Bennekom, 1978). In the Sierra Leone estuary, the maximum amount of chlorophyll is deposited on the shelf during the rainy season owing to the flushing effect, and the volume of microflora increases in the estuary as the outflow decreases (Bainbridge, 1960).

The impact of the Zaire's waters on production is far less obvious. Close to the river mouth, there is an increase in nutrient salt content which van Bennekom et al., (1978) attribute to an upwelling induced by estuarine circulation. However, the river phytoplankton dies rapidly on arrival in the sea, and the highly turbid and opaque waters at the river mouth permit planktonic growth only at a great distance from the estuary, at salinities of > 30%. These blooms sharply cut the nutrient salt content (van Bennekom et al., 1978). The arrival of the Congo's waters off Pointe-Noire is always accompanied by a drop in phosphates, chlorophyll and production; only silica enrichment persists (Dessier, 1981). It is assumed that the blooms observed at a distance from the estuary exhaust the nutrient salts available, or at least induce a nutrient imbalance (Cadée, 1978). During the low-salinity seasons, Oithona nana and Paracalanus scotti zooplankton are rare off Pointe-Noire, while Pseudodiaptomus serricaudatus becomes abundant (Dessier, 1981).

The outflow of the Niger into the sea also does not perceptibly enrich the coastal waters. Bainbridge (1972) notes that there is almost no phytoplankton off the coast of Nigeria, while during the same season (July-August) diatoms were abundant off Cape Three Points (during a period of upwelling, it is true). The zooplankton content is also low. Is turbidity too high, or are the nutrients retained by the delta mangroves?

3.2 Lagoons

These stretches of shallow fresh or brackish water are often transit zones for river waters before they reach the sea. Some lagoons communicate with the sea only temporarily, during the rainy season, and may become extremely saline (70%) during the dry season. They are periodically recolonized by benthic marine species which do not breed there, but only small areas of the lagoon are involved, particularly in Ghana (Lawson and John, 1987).

The Ebrié lagoon, connected with the Comoé river, is the biggest lagoon in West Africa. Since the opening of the Vridi Canal in 1951 it has been subject to marine influence. The average annual inflow of freshwater comprises three times its volume, and of sea water, 14 times the volume of the lagoon. There are two floodwater periods, from the coastal rivers draining forest watersheds, in June and September. There is a single, much more powerful flood, of a Sudanian river, the Comoé in September-October (Figure 2). Marine influence, which is almost nil during the flood period, peaks during the low-water period from December-May. Wind, tidal currents and flushing currents bring about extreme turbulence.

Circulation is fluvial or estuarine depending on the season and the sector. In the western sectors, where water renewal is lowest, salinity never exceeds 5%, while in the strongly hydrodynamic regions near the canal salinity ranges from 0 to 33% between the flood and the low-water season. In the eastern region near the Vridi Canal, the water is
probably renewed between 10 and 30 times a year, while in the peripheral regions renewal may occur only once every two years (Dufour, 1982a).

In the most isolated and shallowest regions, wave action resuspends the sedimented materials and maintains high regenerative production. The lack of transparency limits production. Mineralization of this organic matter may create anoxic pockets in isolated pools. Phytobenthic plankton probably contribute no more than 10 percent to autotrophic production (Dufour and Durand, 1982).

Nitrogen and phosphate concentrations increase between the low water and the flood seasons. Oceanic waters during the hot season are the poorest in nutrient salts, followed by upwelling waters, savanna and forest inland waters, and waters of ramwater origin; the richest waters are those around Abidjan. The sestonic biomass is limited mainly by phosphorus in inland lagoons and by nitrogen in estuaries. Productivity of oceanic waters is limited more by nitrogen than by phosphate, as is the case for inland savanna waters and urban effluents, although to a lesser extent. Forest waters, on the other hand, are poor in phosphorus (Dufour et al., 1981). The arrival in the sea of "forest" waters does not, therefore, result in the development of the same planktonic communities as does the arrival of "savanna" waters.

Production is almost four times higher in closed than in open water bodies, but in the first case it is maintained entirely by internal recycling. In the second, it is boosted by nutrient salts from inland and enriches the plant matter content of the estuarine complex.

The average plant biomass is equivalent to that of a region of moderate upwelling, but concentrated within a depth zone of a few metres. Production is at its highest during the low water season and at its lowest during the rainy and flood seasons: the net average is 236 g C/m²/yr, 1.4 times greater than that of the continental shelf. Less than 10 percent of this production enters the sediments. The exportation of phytoplankton to the ocean is 2.5 times greater than the total combined inflow from inland and from the ocean. This, together with the exportation of mineral salts and of dissolved organic matter and particles, is responsible for 9 percent of the net annual production of the continental shelf off the lagoon (Dufour, 1984a).
The typical lagoon zooplankton population is neither very diversified (Acartia clausi, Oithona brevicornis, Pseudodiaptomus hessel) nor very abundant (Arfi et al., 1987). Its biomass is only 2.6 percent of that of the phytoplankton (Dufour, 1984b). Only one-third of the phytoplankton biomass is thought to be eaten by herbivorous species. This low figure is attributed to the absence of panarthropic species (Rotifera, Ciliacea) capable of taking rapid advantage of abrupt growths. From primary to end-level production (fish and crustaceans) the yield is low (less than 1 percent). Control of the zooplankton by Mysidacea, and the absence of filtering fish outside the estuary zone, are responsible for this low yield.

The most common macrobenthic taxons are polychaetes, decapod crustaceans, gastropod mollusks and bivalves. There are no echinoderms. Four types of population have been identified; two of them with Crassostrea gasar - Brachydonotes tenuistratius, and Anadara senilis - Tagelus angulatus are characteristic of bottoms near the opening to the sea where water renewal is good. The other two, with Pachymelania aurita, - Congeria ornata and Corbula trigona - Iphigenia spp. respectively, are typical lagoon populations. The first predominates in the eastern, and the second, in the western side of the lagoon. There are intrusions of euryhaline marine species, particularly polychaetes, into the bottom of the lagoon, near the outlet to the sea during the dry season which disappear during flood periods. Elsewhere the faunistic composition of the populations is much more stable. The small bivalve Corbula trigona is important because of its abundance and because it is eaten by malacophagic fish. As compared with other West African coastal environments, the benthic fauna of the Ebrié lagoon is diversified, rich and productive (Zabi and Le Loeuff, 1993).

In short, the lagoon ecosystem is kept productive by intensive renewal promoted by a heavy inflow of nutrient salts of land origin and exportation of living matter to the sea. The system acquires a certain maturity only in isolated peripheral regions where regenerative production prevails.

At sea, the flood periods coincide with the main upwelling season, and it is only as an indirect result of the dry years that the role of continental sediment production has been revealed (Binet, 1983a, 1983b). Specific phytoplankton populations develop during the periods when the lagoon waters are flushed into the ocean. A first peak occurs during the first coastal rains: some years coloured water has been observed. But it is at the end of the upwelling season, at the start of the big flood, that the biggest algal biomass is produced (Dandonneau, 1973). Silica is rapidly consumed by the growth of diatoms, and being slow to remineralize, becomes the first limiting factor in the upwelling waters. But at the time of the big flood, dissolved silica is brought down in abundance by the waters originating in the savanna. This additional supply permits greater planktonic growth than would upwelling alone.

Because of less rapid kinetics, the zooplankton biomasses (Figure 2) develop only moderately during the first part of the outflow season and peak in September when the last upwellings coincide with the start of the big flood (Binet, 1983b). Since the beginning of the seventies the outflow of the Sudanian rivers has been considerably reduced. During the upwelling and flood period, the marine zooplankton biomasses near the Vridi Canal have failed to achieve their pre-drought levels.

A few brackish water copepods are found among the coastal plankton at the time of the first flood (Acartia clausi, Pseudodiaptomus serricatus). But on the whole it is opportunistic populations (Centropages chierchei, Temora turbinata) which profit from the phytoplanktonic blooms induced by the combination of upwelling and deposits from the land (Binet, 1983b).

### 3.3 Hypersaline estuaries

When the bed of a river is near sea level, sea water may ingress during the low-water seasons. If the freshwater inflow is less than the loss through evaporation, salinity becomes higher than in the sea. This happens in the Senegal and the Casamance, particularly during the current drought. Before 1900, marine water intrusions into the Senegal River during the dry season were negligible; but in 1959 they reached 150 km upstream, and in 1978, 200 km (Gac et al., 1986). The Senegal has only a modest rate of flow (3.5 m³/s in May to 3 070 m³/s in September, average 1960-1976) and evaporation raised the salinity to 40/20. To prevent these incursions of saline water, the Diama anti-salt barrage, 50 km from the outlet, was brought into operation in 1985. The sluice gates are opened to allow the passage of the flood, which arrives abruptly at the beginning of August and persists until the end of November. In the estuary the marine waters are then rapidly pushed back; in two days salinity drops from 40 to 20/00 at Saint Louis, and in the sea a plume of freshwater 10 m thick occurs. The sluice gates are closed at the end of the flood and the salinity of the estuary gradually rises. Water is released occasionally during the dry season to limit the water level above the dam. Each time there is a repetition on a reduced scale of the sequence flood-desalinization, closure-resalinization and evaporation-oversalinization process (Cecchi, 1992).

During the flood period the flushing effect is considerable and turbidity is high, so much so that although the content of silicates and nitrates is high, the chlorophyll content in the estuary remains low. The chlorophyll content increases with salinization of the water and peaks when salinity is >25/100, and such water is deep down, and near the sea. Taxonomic diversity and average cell size diminishes the further up-river one goes. Algae from the lake behind the dam suffer massive mortality from osmotic shock upon reaching the estuary (Cecchi, 1992).

Up to 1969 the estuary of the Casamance, a long (230 km) and narrow (1 to 10 km wide) channel with a very low rate of flow (average 1968-1983: 2.7 m³/s), was only very slightly hypersaline (40/20 in June, at 80 km from the mouth). But where salinity did not exceed 10/00 in 1969, it reached 70/00 in 1984. At the end of the 1986 dry season salinity reached 170/00 at a location 220 km from the sea. The deficit of freshwater (Figure 3) plus high evaporation leads to the development of the dry season in a salt plume which travels upstream, like a piston, at a speed of 0.1 to 0.5 cm/s. The estuary functions in reverse and there have been several years where the water has remained trapped within the river (Debenay et al., 1989). The mixing by tide and wind maintains vertical homogeneity, but sporadic accumulations of brackish water occur in the deep strata a hundred or so kilometres inland from the coast (Pagès et al., 1987).

A considerable amount of organic matter comes from the river banks (particularly from Phragmites), and production is almost entirely due to in situ regeneration of the organic matter. The chlorophyll content is moderate in the downstream and middle reaches of the river and higher in the upper reaches, with a very clear maximum of peak salinity upstream. Concentrations increase in the dry season and drop during the floods. Oxygen is close to saturation, except a long way upstream near the bottom, due to the high organic sediment content.
the inland freshwater fauna has been almost totally replaced by arm men species. In the Gambia, whose hydrology resembles that of the Casamance before the drought, suggests that abundance decreases from the mouth up to the salinity maximum, then increases a little upstream. The populations of foraminifers, zooplankton and fish become oligo or monospecific (Debenay et al., 1982). Upstream only a few insect larvae survive. Macrobenthic production is relatively low up to a salinity of 70′/,, Three species of Acartia (A. plumosa, A. clausi and A. gran) predominate successively as one proceeds from the slightly desalinized (<34′/,) to the hypersalinized waters (>48′/,). (Diouf and Diallo, 1990). In the most saline waters only A. gran and chironomid larvae are to be found (Diouf and Diallo, 1987). Upstream only a few insect larvae survive. Macrobenthic production (Crassostrea gasar, Anadara senilis) is low in the downstream part, then nil because of the salinity (Pagès, 1992).

In the most neritic part of the continental shelf area, above relatively muddy bottoms, demersal fish assemblages are dominated by the Sciaenidae, in particular Pseudotolithus senegalensis. They also include Ariidae (Arius heudelotii, A. laticlips), Ephippidae (Drepane africana), Polyenimidae (Galeoides decandactylus), Cynoglossidae (Cynoglossus senegalensis, C. monodi and C. browni) and Pomadasyidae (Pomadasys jubelini). In the typically estuarine regions assemblages change somewhat; Pseudotolithus typus and Pentanemus quinquarius replace Pseudotolithus senegalensis and Galeoides decandactylus respectively and Pteroscian peli, Arius spp., and Dasyatis margarita are relatively more abundant than over the shelf (Longhurst and Pauly, 1987).

For the Ebrie lagoon, Durand et al., (1982) distinguish between (1) "true" estuarine forms whose entire existence, in particular reproduction, takes place in a mixohaline environment; the most typical of these very euryhaline species are the Cichlidae, Tylochromis and Tilapia; (2) "true" estuarine forms, which spawn in fresh or very slightly brackish water (e.g., Pterygoplichthys), and (3) estuarine marine forms which spend only part of their lives in the lagoon. Most of the estuarine marine forms breed at sea, near the coasts, and the juveniles of Ethmalosa fimbriata, one of the main species caught in the lagoon, is an exception, because it spawns in the lagoon.

In the region most influenced by the sea, some twenty species constitute an assemblage which has been remarkably stable over two decades (observations in 1962 and 1981). The highly variable environment prevents them from achieving a highly structured organization (Albaret and Ecoutin, 1990). Three crustaceans are fished in the lagoon:
Macrobrachium vollenhovenii, which breeds in rivers or on the edge of brackish waters, so that adults are found in the lagoon only near the mouths of the rivers; Penaeus notialis, which spawns at sea; and the crab Callinectes ameriacola, which spawns in the lagoon near the openings to the sea. The post-larval stages of Macrobrachium and the post-larval and juvenile stages of Penaeus also develop in the lagoon.

In the Gambia, fish are most abundant in the lower part of the estuary, which is greatly influenced by the sea (Dorr et al., 1985). There, shoals of pelagic fish (juvenile Sardinella maderensis and Ethmalosa fimbriata) constitute 81 percent of the catch. Detritivorous fish are numerous, particularly near the banks and in the bolons, or creeks, doubtless because there they find greater protection and more organic matter. Chrysichthys nigrodigitatus, which tolerates turbidity and oxygen deprivation, constitutes 44 percent of the catches in the bolons.

In two Guinean mangrove estuaries most are marine species, half come only to feed and spawn. Fifteen species live there more or less permanently and 12 spend only the first stages of their life (Boltachev, 1991). Among the adults, Cichlidae, Sciaenidae, Ariidae and Polynemidae are the most numerous. Tilapia guineensis, Pseudotolithus elongatus and Arius latiscutatus are the most abundant in the experimental fisheries. The local fishermen also catch great numbers of Ethmalosa fimbriata, Chloroscombrus chrysurus and Liza spp. Ethmalosa predominates during the dry season. The proportion of demersal species increases among the oldest fish, which include freshwater species (Tilapia and Chrysichthys nigrodigitatus). Pelagic species predominate among the juveniles (68 percent Clupeidae, but Mugilidae, Sciaenidae and Carangidae are also found. The number of species decreases during the floods: the Clupeidae (with the exception of Pellonula leonensis), the Carangidae and others (in particular Sardinella maderensis, Caranx senegalus, Lichia amia and Scomberomorus tritor) migrate towards the coastal zone as they grow. The only larvae of demersal species are those of Pseudotolithus elongatus, Ilisha africana, Caranx senegalus, Ethmalosa fimbriata, Pseudotolithus elongatus and Pellonula leonensis that spawn at the beginning or end of the dry season in the mangrove zone. The other species, of which juvenile specimens have been observed in the mangrove, spawn in the estuary in small numbers, or in the neighbouring biotopes.

Most of the species are characterized by a change of ecological niche during development. In fact, despite the abundance of food and the presence of shelter, the difficult estuarine conditions limit reproductive potential (Boltachev, 1991). The predominance of pelagic larvae may be due to their greater ability to survive in open water in this turbulent environment scoured by strong tidal currents. The dominant adult species, on the other hand, are coastal demersals or freshwater species used to muddy substrata.

In the Casamance, all the freshwater fish still found in the Gambia estuary until recent times have disappeared (Albarèt, 1987). Some marine species (Pristis pristis) have also abandoned the estuary. The fish populations are characterized by a big reduction in diversity upstream (Figure 4). Massive mortality may occur when the salt plume blocks emigration from the hypersaline zone. Ethmalosa fimbriata predominates downstream, and is caught in waters as saline as 82%o. Surotherodon melanotheron tolerates slightly higher salinity and predominates in assemblages further upstream. Tilapia guineensis has the same distribution but is less abundant, except far upstream where it is able to multiply rapidly. These fish may be phytophagous or detritivorous, pelagic, demersal or territorial, and they exploit different environments and so compete little, and predation is not common. The unstable, harsh environment, with its swings in trophic resource abundance, leads to special adaptations: food opportunism favouring short food chains, high fecundity and smaller size at maturity. The exploitable biomass is large, but because of the size of the fish is of low commercial value.

![Figure 4. Reduction of number of fish species in proportion to rising salinity in Casamance. Right-hand side represents a linear adjustment for salinities > =35%o.](image)

The Arguin banks, particularly the Baie de Saint Jean, is a hypersaline region. Nevertheless, brackish water species are to be found there: Sarotherodon melanotheron, Mugil cephalus, Elops, etc. A number of factors indicate that it might be a fossil estuary (Sevrin-Reyssac and Richer de Forges, 1985). Kaptovsky (1981) thinks that the mullet caught over the Arguin Banks come from spawning grounds in the Senegal River or the coastal lagoons. Alternatively, as in the case of meagre, relic populations may have adapted to the progressive transformation of this fossil river mouth into a marine biotope. In fact, the known breeding grounds of Argyrosomus regius (meagre) are the estuary of the Gironde, the Nile Delta and the Arguin Banks (Quéro, 1989). On the other hand, the presence of Sarotherodon melanotheron in the extremely saline waters of the Baie de Saint Jean, as in the Casamance, is due to swift adaptation.
Ethmalosa fimbriata is probably the prime brackish water resource. In the Ebrié lagoon, E. fimbriata constitutes 60 percent of the catches and 70 percent of the ichthyofauna. This phytoplankton filterer also feeds on zooplankton and microbenthic species (Guiral, 1992). It is very euryhaline, and tolerates high salinity, as in the Casamance, but in general is present over the shelf only during the low salinity period. In Cameroon it replaces sardinelia where the surface water is of low salinity (FAO, 1987) and turbid. It migrates into estuaries and adjacent waters following seasonal changes in salinity and phytoplankton. Juveniles are more abundant in estuaries and rivers, adults are more abundant in estuaries and the sea. In Senegal spawning occurs at salinities between 3.5 and 35°/00, but the bulk of the eggs are probably spawned in salinities of between 5 and 10°/00 (Scheffers et al., 1972). Spawning is almost continuous in the Ebrié lagoon, the preferred zones having salinity above 10 to 15°/00 (Albaret, in preparation). Ethmalosa is capable of large-scale anadromous migrations: in the Gambia it goes as far as 200 km upstream when salt water flows in (Scheffers and Conand, 1976). In contrast, in the Ebrié lagoon, small migrations seem intended to avoid the floodwaters (Charles-Dominique, 1982). It is, therefore, an opportunistic species, in which different populations are capable of different behaviour.

A few mammals live in the lagoons. The manatee, theoretically protected, is in reality hunted to the point where its future is uncertain in some regions (Reeve et al., 1988). A dolphin endemic to West African coastal environments (Sousa teuszii) frequents estuaries and lagoons (Dupuy and Maigret, 1981).

5. FLOODS AND DROUGHT, AVAILABILITY AND RECRUITMENT

Variability of freshwater supply affects the availability of certain species and fishing yields. The position, extension of favourable or unfavourable zones, and in all likelihood their trophic potential, are therefore weather-dependent. Recruitment may also be affected and drought may cause lasting perturbations among fish stocks.

Pseudotolithus elongatus (Bobos) are found over a very wide range of salinities - 0.1 - 35.5°/00, in the proximity of estuaries or at the exits of lagoons. In the mouth of the Congo, catch per unit of effort varies with river flow; the best catches correspond to flood periods and the worst to slack flows (Figure 5). Bobos prefer desalinated waters and their range varies with the extent of the river waters: when the water is low there are few outside the estuary (Le Guen, 1971). The availability of river water also affects sexual maturity; the percentage of mature females peaks in flood periods and spawning apparently takes place in highly desalinated water near, or within, the estuary.

The opposite effect - flood-diminished fishery yields - is also possible, however. In the Cross River estuary in Nigeria, trawl catches, and this would include Pseudotolithus elongatus, drop during the flood period (Lowenberg and Kunzel, 1991). Catchability drops because the fish are distributed over a larger expanse of water, but also because the stock leaves the upstream area of the estuary for the continental shelf when the circumstances are favourable. The area propitious to estuarine species moves seaward during high waters, but as the fishery is confined to the estuary, yields drop in contrast to what happens in the mouth of the Congo, where bottom trawling takes place on the shelf and outside the estuary.

The catchability and/or the recruitment of stenohaline marine species can sometimes be favoured by drought. In 1972, the first year of the great drought, the Sardinaella aurita fishery was exceptionally good in Ghana. This stenohaline species normally stays some distance from the coast and from freshened coastal waters. In 1972, the absence of coastal freshening allowed large quantities of juveniles to approach the shore where they were fished in large numbers. The stock, devoid of spawners, collapsed over the next few years. The recruitment of S. aurita is apparently dependent on plankton abundance during the early life stages, and hence on upwelling intensity, but S. aurita availability is inversely proportional to river flow (Figure 6), (Binet, 1982). After the recovery which followed the overfishing of S. aurita, the entire dry decade of the eighties produced excellent catches of this species (Binet et al., 1991).

In upwelling areas, the influence of freshwater flows into the coastal ecosystem is difficult to identify because there is often a reverse correlation between the intensity of deepwater upwelling. Indeed, the winds parallel to the coast which usually generate upwellings do not carry moisture over the continents, and the waters which well up from the bottom, by cooling the lowest atmospheric strata, prevent the rise of moisture which generates rainfall. In Morocco, Belvèze (1991) noted that several successive dry years will produce a bigger sardine catch in the first year and the cpue drops during the dry period, but after the recovery which followed the overfishing of S. aurita, the entire dry decade of the eighties produced excellent catches of this species (Binet et al., 1991).

![Figure 5. Congo outflow (m³/s) and daily average catches of Pseudotolithus elongatus by Pointe-Noire trawlers. According to Le Guen (1971)](image-url)

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In the longer term, the ecological changes which accompany rainfall variation seem likely to affect recruitment. The catch of shad (an anadromous species) processed by the Kénitra cooperative in Morocco dropped between 1969 and 1984 (Borki, 1990). Pollution and diminished rainfall are the probable causes.

The major phenomenon in West African fisheries in recent decades was the unprecedented development of *Balistes carolinensis* (Caverivière, 1993). This species, formerly rare, became dominant from Senegal to the Bay of Biafra from 1970 to 1980. Drought-related environmental modifications are thought to be partially responsible for this proliferation. The massive appearance of *Balistes* at the end of 1971 and beginning of 1972 corresponds to an abrupt drop in river flow. Diminished *Balistes* abundance throughout West Africa coincides with a moderate resumption of rainfall in 1985-86.

These changes may have inhibited competing species and modified water transparency and planktonic diversity and composition. Balistidae frequently inhabit coralline zones with their limpid and salty waters. Some species lay their eggs in nests which they protect, a behaviour which can only work effectively under conditions of low turbidity, and hence in the absence of major inputs of river waters. There are, in fact, no strong concentrations of *Balistes* in the freshened waters off Sierra Leone (<28°N).

Figure 6. Ratio between catches of Sardinella aurita in Côte d’Ivoire and Ghana, and Bandama and Comoé river outflows according to Binet (1982). In A the stock is considered in its normal state (before collapse and after recovery), in B the stock is recovering from overfishing in 1972.

In *Côte d’Ivoire*, the fishing yields for several species changed at the time of the *Balistes* explosion. The cpue of *Brachydeuterus auritus* and of *Ilisha africana* dropped, whereas the cpue of *Pseudotolithus* spp. and of the Sparidae increased as of 1974, as did the cpue for *Pomadasys* as of 1972-73 (Caverivière, 1993). The drop in *Brachydeuterus auritus* yields might be due to interspecies competition with *Balistes*. The two species are semipelagic and their ranges overlap. *Pseudotolithus* spp. and Sparidae species, on the other hand, would have benefited from a reduced fishing effort, because trawlers avoid fishing grounds where *Balistes* is heavily concentrated.

In the rivers and estuaries, the drought is perceived as a cause of diminishing resources. The shrinkage of flooded areas reduces the habitat, particularly the spawning zones. In the end, the catch falls even further in that the fish become more vulnerable. This has been observed in the central Niger delta (Lae, 1992a) and also in the lower reaches of the Senegal and Gambia Rivers. The production of the Senegal River valley and delta during
the drought is estimated to be half what it was before the drought (Diouf and Bousso, 1988). The artisanal catch in maritime and estuarine Gambia plummeted between 1975 and 1985, particularly in the floodplains, which were dry most of the time by then (Dorr et al., 1985).

*Penaeus notialis* is the main penaeid shrimp exploited along the West African coast. Spawning occurs at sea. At the end of a plankton phase, which lasts about one month, the post-larvae penetrate the estuaries and lagoons, aided by estuarine water circulation. The subadult shrimp return to the sea three months later (Lhomme and Garcia, 1984). Artisanal fisheries exploit the juvenile phase during the return migration, whereas adults are fished on the shelf by industrial trawlers near the estuarine or lagoon zones. Trawl catches are usually better in turbid waters although the adults avoid freshened waters during rainy and flood periods by migrating to greater depth (Garcia, 1977).

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Inter-annual catch variations exhibit complex and apparently contradictory relationships with salinity (i.e. rainfall and river flow) in the estuaries, where larval development takes place. At the mouth of the Zambezi, Gammelsrod (1992) observed a positive correlation between river flow and the catches of young and adult *Penaeus indicus*. During the years 1960 and 1970 Lhomme and Garcia (1984) note two contrasting relationships for the stocks of Saint Louis in Senegal and of Roxo-Bissagos (Casamance-Guinea-Bissau). There is a positive correlation with the catch at sea of the first stock and the flow of the Senegal River, whereas the catches of the second stock are in inverse proportion to rainfall in the Casamance watershed (Figure 7). Such contradictory observations are not unusual. The catch/rainfall ratio is generally observed to be positive in habitually dry regions where river water inputs are low, and there is a negative correlation in rainy areas where freshwater supplies are more abundant.

The Casamance estuary is a special example of a changing trend in response to drought and the analysis of Casamance fisheries helps to explain the preceding contradictions (Le Reste, 1992).

Artisanal catches initially rose together with salinity from 1965-1983 before collapsing in 1984. Water renewal in the estuary is very slow and salinity therefore depends on the rainfall of the two previous years. There does seem to be a negative linear relationship, however, between the catch and the rainfall of the two preceding years (Figure 8a).

Capture weight is related to stock biomass and hence to the size of the migrating shrimp. Final shrimp growth size, however, depends on salinity and current speed, in accordance with the square of the salinity and in inverse ratio to the speed of the current (Figure 8b) (Le Reste, 1987). According to this model, size at migration peaks at a salinity of 29°/o (close to the osmotic sub-adult point of equilibrium); but shrimp size falls off strikingly at salinities below 10°/o or above 50°/o. Within these boundaries, size depends primarily on current speed which, in Casamance, drops progressively upstream.

Capture weight also depends on the numbers of shrimp caught and this, rather than spawning intensity, probably depends on the surface area of the zones favourable to postlarval (5 < S < 50°/o) and sub-adult (20 < S < 50°/o) growth.
For a number of years, increasing salinity allowed the shrimp to colonize areas upriver, which produced an increase in migration size and numbers. In 1984, however, the water became so supersaline that the shrimp remained blocked downriver where salinity is more stable and thus migration size was smaller due to the current speed and there were fewer shrimps. Interestingly, however, the peak catches recorded were at salinities much higher than that of sea water.

The harvest of mangrove oyster (Crassostrea gasar) is an ancient practice that is still very much alive in the Casamance (Cormier-Salem, 1987). There was a very active trade in dried oysters up to 1950. The harvest was particularly important during the drought years when it was impossible to grow rice. But the riverbank soil became increasingly permeated by acid sulphates and salts and the groundwater became very salty. Upriver from Ziguinchor, the mangroves are now nothing more than dead wood. There was a spectacular drop in the Rhizophora mangle zone in favour of a degraded mangrove or Sesuvium carpet. The "tannes" [tannin compounds] have risen by 73 percent to the detriment of the waters and the mangrove. The habitat favourable to oysters has shrunk substantially. Last of all, spawning and growth are also adversely affected by the salinity. The drought-related drop in agricultural activities is no longer offset by the oyster harvest, which was traditionally a women's job, and this has produced rural emigration. Only the resumption of a favourable rainfall pattern could reverse this trend.

6. DISTURBING FACTORS: POLLUTION, DEVELOPMENT

Development-generated environmental disturbances are frequently aggravated by drought. In the Casamance, a relatively small drop in mean rainfall (300 mm/yr) has thrown a "rice basket" ecosystem into total disarray. The reduced seaward flow of freshwater is a further and frequent cause of pollution.

The existence of amphiotic species heightens the impact of pollution at the boundary of continental and maritime environments. Domestic and industrial wastes increase the organic matter content. The BOD4 of the urban effluents of the city of Abidjan is 330 mg/l, compared to 0.8 mg/l for ocean waters, 0.4 for savannah waters and 1.8 mg/l for forest waters. The effluents represent only 111 of the BOD within it. The eutrophication which is produced at some distance from the source of the effluents leads to chlorophyll concentrations three times higher than those found in rural areas, and doubles the chlorophyll production. In 1975, pollution was responsible for 7 percent of the phytoplankton production in all of the Ebrê lagoon (Dufour, 1982b). In the Niger delta, oil spills from operating wells are frequent and the river waters carry numerous particles of tar. One-fourth of the pesticides applied to the industrial plantations are thought to be drained by rainwater runoff into the lagoons or sea.

In Abidjan, the Bay of Bétiëri illustrates a different example (Arfi et al., 1990). Pollution is flushed out to sea via a destratification caused by an influx of cold sea water and high tides. The Bay of Bétiëri, which is isolated, although close to the Vridi Canal and sea closed by dykes, is heavily polluted by industrial palm oil mills. Vertical stratification is much greater during the rainy season (the flushing effect is much weaker then) and during low tides. Mineralization and phytosynthetic activity (peak dissolved surface oxygen) are high at that time. At the beginning of the long dry season, maritime influences grow stronger, particularly during upwellings, and the density falls off. At each new tide the sea water penetrates, cooling the surface waters and destroying the stratification. The high-tide periods amplify the destabilization and promote renewal of the system. The effect of this is a drop-off in primary production and mineralization. Biodegradation is also slowed by the high salinities. The reduction of the density gradient is followed by the disappearance of the heavy ammonium and phosphate loads accumulated during the anoxic hypolimnion. Thus the system passes through a succession of stable phases during which the following take place: mineralization, oxygenization of the epilimnion and deoxygenation of the deep layer, and unstable phases during which these processes are interrupted and the hypolimnion is reoxygenated to some extent.

River valley developments have strongly perturbed water regimes, all the more so in that most development took place at the onset of the long drought. Freshwater outflows are artificially regulated, and floods are not allowed to crest. The mineral, organic and solid matter content is reduced by sedimentation within lake dams, at the bottom of which anoxic zones may form. Effluent contents differ in accordance with the height of the sluices above the bottom.

Hydro-electric dams were built in Ghana (Akosombo on the Volta) and in Côte d’Ivoire (Kossou, Taabo on the Bandama) at the end of the 1960s. Filling the lakes behind the dams, which took several years, resulted in a heavily reduced seaward flow with infiltrations and evaporation reducing the flow still further. In the Volta estuary and adjacent lagoons, the quantity and quality of the freshwater changed considerably. Shrimp and oyster production ceased in the lagoons, and a record low in shrimp production was recorded (Mensah, 1979). At the mouth of the Bandama, where the flushing effect is low, the channel became obstructed. It was reopened by dredging at the fishermen's request. However, this opening created further problems (cf. below). The Manantali dam (1 200 km from the mouth of the Senegal River) was intended for irrigation and to generate electricity, but it severely cut the volume of water downstream and reduced flooded surface areas, destroying certain spawning grounds.

The anti-salt barrages, designed to preserve agricultural land from salty water and to make them irrigable, are located further downstream, in the estuarine area. They block the outflow of freshwater to the sea except during the heaviest flooding. They also prevent migrations of amphiotic species, and particularly the upstream movement of euryhaline species (shrimps, crabs, oysters). The Diama dam, 50 km from the mouth of the Senegal River, will probably improve upstream fish production by refilling the resulting lake, but will produce a reduction in fish productivity within the estuary. Further, the freshwater species carried down toward the estuary by the floodwaters will no longer reach their destination and catadromic species will be unable to spawn in the brackish waters. Major mortalities of migratory species are observed at certain times. However, the feared elimination of the bongo, Callinoctes and the pink shrimp in the Senegal River estuary did not take place. Lastly, the irregular nature of water releases and hence of downstream phytoplankton surges has augmented the "unpredictable" nature of this environment, favouring colonization by opportunistic species of low commercial value. Indeed, an increase in the numbers of tilapia and mullet has been observed.

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4 Biological oxygen demand necessary to oxidize organic waste matter, 3 j at 30°C.
The proposed Balingho dam, 120 km from the mouth of the Gambia River, would entail the disappearance of the upstream mangroves and reduce their presence downstream along nearly 30 km of river bank. Mangroves do poorly near the sea and where the waters are supersaline, as in Casamance, and bare ground may be the final outcome. The result would be a loss of organic matter input and a drop in estuarine production (Dorr et al., 1985). The shrimp fishery can expect to see favourable initial trends (larger seaward-migrating shrimp) but the final result could be a reduction in the stock due to a shrinking adult habitat (river-exported muddy areas) and a drop in post-larval recruitment, as it seems unlikely that the post-larval stages could reach the river mouth unguided by a falling salinity gradient. The utilization of fertilizers, herbicides and pesticides may also have a toxic or at least dystrophic effect (Van Maren, 1985).

It would be preferable to extend the anti-salt barrages on a small scale in the Casamance to allow better monitoring of the chemical modification of the soil. This is similar to the Diola practice prior to the drought, when they prepared their rice fields within the mangrove zones (Gilles, 1988).

The artificial opening of a coastal barrier is not without risks. Some of the temporarily open estuarine systems of South Africa shelter juvenile marine fish at certain seasons. To improve the recruitment of these species, winter passes have been opened (Whitfield and Kok, 1992). But the outflow of freshwater necessary to the summer opening brought about the premature closing of these lagoons and the loss of the nursery-grounds which they contained.

Large-scale modifications of the lagoon environment followed the digging of the Vridi Canal in 1950 to create the port of Abidjan. Away from the canal, the Ebrié lagoon took on estuarine characteristics and the fauna acquired a marine component (Zabi and Le Loeuff, 1992). Certain species (e.g. bonga, Callinectes) developed with new fisheries to explore them. A fleet of canoes based near Vridi is able to optimize its yields by working at sea or in the lagoon, depending on the state of stocks. On the other hand, the natural pass of Grand-Bassam where the waters of the Comoé flowed out to sea became closed.

After water lilies accidentally introduced in the lower reaches of the river proliferated, the canal was reopened in 1987 to flush them out to sea (Albaret and Ecoutin, 1989). A seawater intrusion occurred, raising the salinity of the Potou and Aghien lagoons to l'/o, in low-water periods, whereas there had earlier been freshwater in the lagoon at such times. The marine fish fauna increased and there was an upsurge of new interest in lagoon fisheries as bonga became much more numerous, and in marine fisheries with the Comoé estuary offering shelter to the big canoes. However, the plans to rear freshwater tilapia (T. nilotica) in the Aghien lagoon were thrown into question, and the high-value lagoon species (catfish: Chrysichthys spp.) have become rare. The most striking consequence was the first appearance of supersalinity (40-42'/o) in 1988 near Grand-Bassam. Subsequently, due to insufficient river flow, the pass closed up again.

To sum up, the accentuated impact of both urbanization and rising sea water levels in the Ebrié lagoon coincided with the impact of the drought.

Mangrove destruction and deforestation are spreading as people attempt to obtain cultivable land, areas for development and fuelwood. The river waters flow faster over cleared land and have a much more erosive effect on the soil. The sediment load and turbidity of both lagoon and river waters increase, the floods become more violent, and the low-water periods more severe. Concrete or macadam-lined channels further accelerate runoff. Ground albedo is also augmented by the destruction of plant cover, giving rise to losses of radiation and the subsidence of the lower atmospheric layers. Humidity equilibration is destroyed and rainfall lessens. All of these processes and changes operate in favour of greater environmental salinity, which is unfavourable to the long food chains that produce higher-value species. The shrinking of flood-prone areas also represents a loss of the habitat propitious to nursery-grounds.

Lastly, a further consequence of the desertification of the Sahel regions is a coastward migration of human populations from the hinterland and the corollary increase in fishing pressure. Wolof fishermen have settled in Mauritania and Casamance (and Fantis and Ewés in Côte d'Ivoire) since ancient times, and the process has now become intensified. Recent movements of Sahel populations toward the Ivorian lagoon and coast have also been noted (Lughinbühl, 1986; Weber and Durand, 1986).

7. CONCLUSIONS

The action of freshwaters on the coastal environment is variable. The kinetic energy of freshwater brings about turbulence and vertical mixing. On the other hand, low freshwater density favours stratification. While the nutrients in freshwater have an enriching aspect, particle abundance also reduces light penetration.

(a) Fafunal population studies show that the boundary regions between fresh and sea water are true ecosystems with their own characteristic fauna and specific communities determined by contact with the ocean, with the coasts, and other estuaries typical of lagoon environments. The coastal benthic fauna exhibits adaptation to changes in salinity, desiccation and falling oxygen content. It is able to swiftly reorganize environments when conditions are again favourable (Zabi and Le Loeuff, 1992, 1993; Le Loeuff and Zabi, 1993). Life cycles are dependent on the wet/dry season alternation. Species diversity is roughly one-tenth that of the marine environment. Diversity diminishes from systems with good inland and marine water inputs (Cameroon, Nigeria, Côte d'Ivoire, Sierra Leone), to those subject to sharply drought regimes (Ghana and especially Senegal). Biomass, on the other hand, can be extremely high.

(b) How these ecosystems operate depends on terrestrial-derived enrichment, which often complements inputs from the ocean, and allows the development of higher primary production than in inland waters or neighbouring coastal waters, under conditions of lesser turbulence and turbidity. The dynamics of these systems depend on alternating conditions so these systems never reach stability. Estuarine-type circulation, with a return of part of the stock in the deep current should permit a certain stabilization of the system, with the older phases exploiting the younger, but such maturity is rarely observed (Frontier, 1978). During periods of drought, the Casamance estuary exhibits a very slow "reversal estuarine" circulation which acts more as a confining mechanism than anything else.

The inputs from river systems, which act to enrich and generate new production, are also the cause of organic exports and a large part of the production is flushed out to
The freshwater deficits caused by drought occasion a marked trend towards marine conditions and this affects the fish and crustacean assemblages in terms of spawning and nursery sites, and fish abundance. The boundaries of the Marine "estuarine" and "inland" biotopes shift inland. In the Casamance estuary, where the drought is most severely felt, there have been profound changes in the fauna: the multiplication of small species in the supersaline regions have not compensated for the loss of other forms. The only beneficiary of this state of affairs has been the estuarine shrimp (Sardinella aurita). In the long run, it seems likely that diminishing inputs of terrestrial origin weaken production throughout the trophic web.

Major development works, such as dams and lagoon opening plus mangrove destruction, all have the same consequences: loss of mineral and organic inputs, shrinking of habitat favourable to nursery grounds and, in the long run, reduction of fish stocks.

However, the coastal system is only enriched within a certain range of river flows. Where the river outflow is too small (Casamance), export of organic production is not possible, and where it is too great the result will be turbid and turbulent coastal waters and the exportation of terrestrial elements off the shelf (Zaire).

The nature of the nutrient outflow into coastal waters depends on the soils and vegetation in the watershed. Arid regions produce more nutrients than forest watersheds and their effluents are, in particular, rich in silica. This element with its slow remineralization in marine waters could constrain production in coastal waters.

These juvenile systems are in disequilibrium. Primary production, which is subject to extreme variability, is poorly exploited by the secondary and tertiary links of the chain. Copepods (Acartia) are omnivorous and parthenogenetic phytophages (cladocerans, rotifers) few in number. The unpredictability of phytoplancton blooms and the differences between phyto and zooplankton cycles hamper the transfer of primary to secondary production. The importance of the secondary link in the chain is reduced in proportion to the stress laid on the system. In the most highly disturbed zones, which are the hyperhaline zones in Casamance and the estuarine zone in the Ebrié lagoon, the food chain is shortened and most fish are herbivorous. Species assemblages are dominated by a few species typified by early and abundant reproduction, with demographic strategies characteristic of unstable environments. Where the haline variations are fewer, such as isolated parts of Ebrié lagoon or the maritime parts of Casamance, the trophic chains lengthen and far more plankton eaters or carnivores are found.

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Major development works, such as dams and lagoon opening plus mangrove destruction, all have the same consequences: loss of mineral and organic inputs, shrinking of habitat favourable to nursery grounds and, in the long run, reduction of fish stocks.

The management of these resources in their unstable environments and habitats is difficult: the conventional population dynamics models implicitly assume that the environment is a constant. Such models are not accurate where species adaptation to environmental conditions and to fishing pressure, itself a highly changeable factor may lead certain species to modify their population strategies (Lae, 1992b).

8. REFERENCES


INTRODUCTION

The history of land use within catchment basins (e.g. Krug, 1993) and consequent nutrient-loading of river discharges, should play a large part in understanding changes in coastal marine ecosystems, although whole-system studies of these effects are still rare. Estuaries and wetlands (Caddy, 1990) are critical marine habitats of importance to coastal living resources, but also play a large part in reducing land-runoff inputs to coastal and enclosed seas (e.g. Tolmazin, 1985; Cristofor et al., 1993). These critical estuarine ecosystems have been subject to considerable modification in recent decades. At the larger scale of the enclosed and semi-enclosed sea, the "Marine Catchment Basin" or "MCB" concept, proposed originally as a policy framework for semi-enclosed seas, may be useful in encompassing geographical scales of interest to policy-makers and managers, including both the river basins and the semi-enclosed sea they discharge into (UNCED 1991; Caddy 1993). Such a paradigm has special value wherever human activities affecting terrestrial runoff have substantial impacts on a marine system, or are expected to show these effects with further development of the river basin. As such, the MCB provides a more specific framework for treating terrestrial impacts, and provides a framework for those "Large Marine Ecosystems" (LME's: Sherman et al., 1993) when discussing not only man's actions on the marine aquatic system and its living marine resources, but also the repercussions on the estuarine and coastal marine environment, of actions on adjacent land areas that drain into it.

Several recent reviews (e.g. GESAMP, 1988; Howarth, 1993) have focused on the plume-related chemical events and their consequences low in the food chain, but studies on the commercially important components of the ecosystem are less easily located. However, recent experience has indicated not only the key role played by estuarine environments in marine fisheries (e.g. Oglesby et al., 1972; Lenanton and Potter 1987; Houde and Rutherford, 1993; McHugh, 1976), but the potential for significant changes of estuarine faunas under anthropogenic impacts. Such runoff-related changes have also been noted at a larger scale for the ecosystems of coastal and semi-enclosed seas, (e.g. Sutcliffe et al., 1977; Lehtonen and Hilden, 1980; Pucher-Petkovic et al., 1988; Dethlefsen, 1989; Tatara, 1990; Mee, 1992; Caddy, 1993), and these seas often have estuarine characteristics. Environmental changes for these aquatic systems are often accompanied by the replacement of ecosystem...