Chapter 51

CÔTE D'IVOIRE

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The Ivoirian oceanic zone is bordered to the north by the Gulf of Guinea shoreline, stretching from Cape Palmas (7°30W) to Cape Three Points (2°W). The continental shelf is 25–30 km wide, with a surface of about 16,000 km^2. The shoreline, with a length of 530 km, is formed by sandy beaches, shaping a wide arch open to the Atlantic Ocean. A major morphological feature, the "Trou Sans Fond" Canyon cuts the continental shelf in front of Abidjan; there, depths over 1000 m are rapidly reached a few kilometres offshore. Large rivers (Cavally, Sassandra, Bandama and Comoé) drain the country from the north to the south and flow into the ocean either directly or via a lagoon.

The current pattern is dominated by the Guinean Current flowing eastward in the upper layer (average speed and maximum velocity of about 0.5 kt and 2 kt, respectively) and by the Ivoirian Undercurrent running westward in the subsurface layer, (average speed 0.4 kt). Waves from the open sea are very energetic and the swell originating from the South Atlantic Ocean produces a permanent surf parallel to the coastline. Tides are semi-diurnal with diurnal inequality and an amplitude ranging from 0.8 to 1 m. Coastal upwellings occur seasonally along the shoreline, from July to September (major event) and in January (minor event). The prevailing coastal winds are the Monsoon Trade winds blowing from southwest to south-southwest with a speed of about 3–4 m s^{-1}. The climate is governed by the latitudinal displacement of the Inter-Tropical Convergence Zone (ITCZ) separating a humid air mass of oceanic origin (Monsoon period) and a dry air mass of continental origin (Harmattan season). The major rainy season (54% of the annual rainfall, ranging from 1500 to 2200 mm yr^{-1}) occurs generally from May to July, the minor rainy season (16%) occurs from October to November. The major dry season starts in December and ends in March and the minor one between August and September.

The coastline encompasses a variety of coastal habitats including lagoons, estuaries, mangroves, swamps and humid zones. These critical habitats providing spawning grounds for numerous fish, molluscs, birds, manatees and other life forms are now undergoing rapid destruction as a result of intense human activities. Deriving mainly from the history of the country's first contact with European seafarers, nearly all major infrastructures in the country are located in the coastal area. Pollution from these various sources affects the water and their natural living resources. Environmental degradation including critical habitat destruction and loss of biodiversity are among the major impacts. Concerns about the deterioration of the coastal and marine environment of the Côte d'Ivoire coupled with the experiences gained from the country's participation in several regional and international conventions have led to the preparation of a National Environmental Action Plan and also to the vote by the Parliament of a new Outline Law on Environment.

Seas at The Millennium: An Environmental Evaluation (Edited by C. Sheppard)

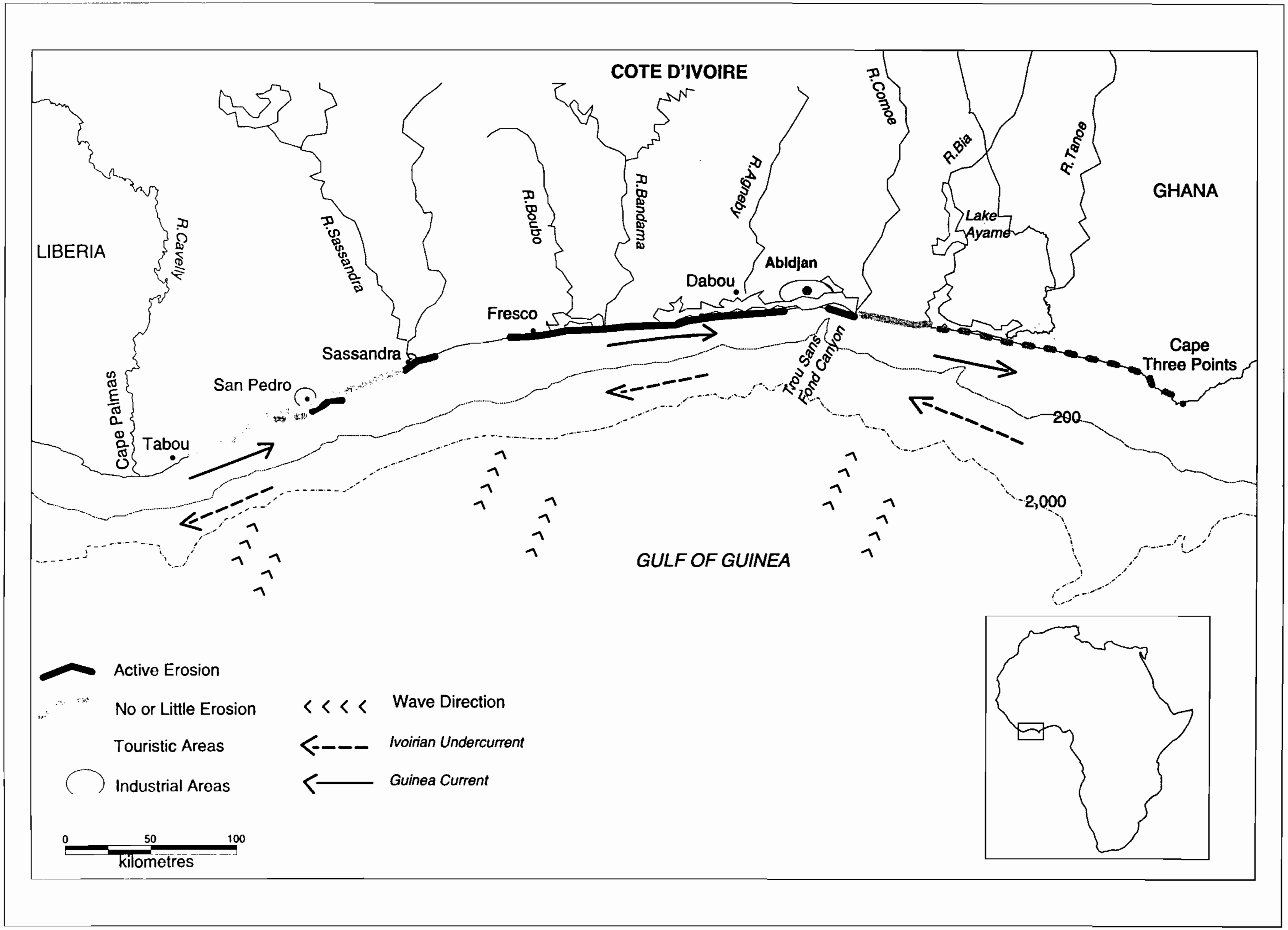

Fig. 1. Map of the Ivoirian oceanic area and coastal habitats.

THE DEFINED REGION

Two syntheses of the studies conducted along the coastal areas of Côte d'Ivoire exist: one mainly of shallow areas of Ebrié Lagoon (Durand et al., 1994), the other concerns other coastal areas (Le Lœuff et al., 1993). A third synthesis (a special issue of *Océanographie Tropicale*, 1983, number 18) describes some pelagic studies conducted in the Gulf of Guinea, near the Equator.

Geological Context and Geographical Limits

The Ivoirian oceanic area is bordered to the north by the Gulf of Guinea coastline, to the west by the Cape Palmas (7°30W, Liberian border) and to the east by the Cape Three Points (2°W, located in Ghana). To the south, the continental slope delimits a narrow continental shelf (25–30 km wide, surface about 16,000 km²). The slope is smooth until –120 to –150 m, then increases sharply (Martin, 1973). A major morphological feature, the "Trou Sans Fond" Canyon cuts the continental shelf in front of Abidjan: there, depths over 1000 m are rapidly reached a few kilometres offshore. Côte d'Ivoire has a land area of 318,000 km² and a shoreline of 530 km. The littoral is made of a series of sandy beaches and forms a wide arch open to the Atlantic Ocean. It can be subdivided into two parts (Fig. 1):

- To the East of Fresco, it is a flat coast, with sandy and monotonous structures of sedimentary origin (Quaternary). Several lagoons (submersed fluviatile basins) are separated from the sea by a littoral bar, built and maintained by waves and currents.
- To the West of Fresco, it is a more complex structure, where the metamorphic basement reaches the sea. Rocky capes with low cliffs alternate with sandy bays.

Water Inputs, From the Continent and From the Ocean

Five major rivers flow into the Gulf of Guinea (Table 1):

- the Cavally River drains a forest area from Mount Nimba (Liberia) to the coastline;
- the Sassandra and the Bandama rivers drain the country from north to south. Both rivers rise in the northern region of the Côte d'Ivoire, which is dominated by savannah vegetation. Dam construction for power production (Buyo on the Sassandra River, Kossou and Taabo on the Bandama River) markedly decreases the freshwater flow from these two rivers;
- the Comoé River also rises in the savannah zone of Burkina Faso. Its natural mouth (Grand Bassam inlet) was closed after the opening of the Vridi Canal and now, the river flows seaward through the Ebrié Lagoon;
- two dams (Ayamé I and II) regulate the Bia River. Its mouth opens in the north shore of the Aby Lagoon, itself opened to the ocean at the Assinie Pass.

Table 1

Main river characteristics. Flow data correspond to the 1980–1996 period

	Draining surface (km^2)	Length (km)	Average flow ($m^3 s^{-1}$)	Minimum flow ($10^9 m^3 yr^{-1}$) and record year	Maximum flow ($10^9 m^3 yr^{-1}$) and record year
Cavally	30,000	700	390	3.8 (1992)	30.1 (1966)
Sassandra	75,000	650	355	6.2 (1984)	33.8 (1962)
Bandama	97,000	1050	173	2.0 (1978)	22.4 (1957)
Comoé	78,000	1160	121	0.8 (1983)	14.9 (1968)
Bia	10,000	290	na	0.8 (1986)	5.2 (1964)
Tanoé	16,000	385	na	1.8 (1958)	7.6 (1968)

na: Not available.

These large rivers are characterised by high flow during the flood season and by low flow during the dry season. All of them have permanent openings to the Gulf of Guinea, and their floods strongly influence the marine system. Several coastal rivers reach the ocean via a lagoon (Tanoé River into the Aby Lagoon, Mé River and Agnéby River into the Ebrié Lagoon, Boubo River into the Grand Lahou Lagoon). Other minor forest rivers have their mouths west of Fresco. In most cases, they have a low flow during the dry season; then, the ocean transport rapidly builds a sandy ridge, closing the mouth and forming little lagoons. They flow again seaward during the flood season.

The coastal ocean along the Côte d'Ivoire shoreline has a morphological, geographical and dynamical unity, under a seasonal continental influence and under a permanent oceanic influence. It is widely open to the Atlantic Ocean, but its functioning is driven by local forces. Biological processes governed by the structure characterise both the pelagic and the benthic systems. Major changes occur in July and in January, when cold and rich deepwater reaches the surface.

SEASONALITY, CURRENTS AND NATURAL ENVIRONMENTAL VARIABLES

Ecological processes in the area are largely governed by seasonal or periodic phenomena, occurring over a wide frequency range. These processes include lateral hydrodynamics (waves and currents), vertical oscillations (thermocline migrating up and down), continental water inputs (during the flood) and climatic variations (solar radiation, winds). Some aperiodic phenomena (e.g. strong winds) may sometimes affect the upper layer of the water column.

Currents and Hydrodynamics

Currents

Dominated by two systems, the current pattern is simple. The Guinean Current (GC) flows eastward in the upper layer (0–30 m depth), with an average speed of about 0.5 kt and a maximum velocity close to 2 kt. The Ivoirian Undercurrent (IU) runs westward in the subsurface layer, with an average speed of 0.4 kt. Both current systems are permanent, and their movements at the surface induce a powerful coastal drift. However, superficial circulation is spatially and temporally affected by high variability (Colin, 1988):

- horizontally, the GC can extend southward, but then its speed and intensity decrease rapidly;
- vertical inversions occur from January to March and in October, as a result of a southward shift of the GC allowing the IU to reach the surface;
- the GC reaches its maximum intensity from May to August and from December to February. The IU velocity is high from July to November and from February to April.

Waves

These are from the open sea and often very energetic. The swell originates during the austral winter from the South Atlantic (50–60°S), and produces permanent surf parallel to the coastline. Breaking waves induce littoral transport, favoured by surface currents (Fig. 1). In the western part of the littoral, erosion is weak (the load of sand carried is 200 km^3 yr^{-1}), since the shore is rocky and capes alternate with bays. High erosion characterises the central zone, and the beach ridge is actively eroded (800 km^3 yr^{-1}). Since the opening of Vridi Canal and the construction of a protection pier, transport between the central and the eastern zones is interrupted. Most of the sand coming from the west either goes into the Trou Sans Fond Canyon or contributes to the growth of beaches adjacent to the western side of the pier. Erosion is very active in the eastern part of the littoral between the Vridi Canal and Grand Bassam (400 km^3 yr^{-1}). Consequently, these processes modify the shoreline, move the river mouths and destroy coastal buildings. They are also a threat to San Pedro and Abidjan's harbours and for the sites located east of Vridi, industrial (oil refinery, airport) as well as tourist facilities such as hotels along the beach.

Tides

These are semi-diurnal with diurnal inequality. Tidal amplitude is low, ranging from 0.8 to 1 m. The average seawater level is a good indicator of the occurrence of the upwelling events. It is low in January and from July to September, high between May and June and from October to November. Seawater level fluctuation is around 15-cm ± the tide signal.

Wind

Monsoon Trade winds blow 10 months a year from southwest to south-southwest. They are weak (3–4 m s^{-1}) and regular, characterised by diel rhythms. Their speed increases during the boreal summer (4–6 m s^{-1}). In January and February, Northeast Trade winds (also called Harmattan) blow from north-northeast to northeast. Despite their reduced speed, the enormous sandy and dusty load they carry in the atmosphere induces high nebulosity.

Coastal Upwellings

These occur seasonally along the shoreline, from July to September (major event) and in January (minor event). The thermocline moves upward under the combined action of winds and currents. Intensification of zonal wind along the shoreline causes a Kelvin wave trapped at the Equator. The eastern border of the basin reflects this wave as secondary Rosby and Kelvin waves, which in turn induce the upward movement of the thermocline. During the boreal summer, local wind speed increases. Its direction rotates slightly eastward, and becomes more parallel to the coast. Therefore, prevailing winds contribute more to the vertical movement, while the GC speed increases during the same period. Coastal morphology and dynamic processes enhance locally this phenomenon (cape effect). More intense and more lasting major events are observed between Tabou and Sassandra. In this part of the coast, minor upwellings always occur. From Fresco to Abidjan, the main upwelling decreases in intensity and in duration and the minor event is generally weak, sometimes absent. East of Abidjan, cooling is reduced during the main event, and the minor upwelling sometimes occurs. Interannual variability of these events is high, and nutrient enrichment varies considerably (Arfi et al., 1993b). For several years, cooling has increased in the western part of the littoral, particularly during the minor cold event.

Climate

The climate of the coastal zone is governed by the latitudinal displacement of the Inter-Tropical Convergence Zone (ITCZ). Alternation of rainy and dry seasons is regulated by zonal and seasonal variations of the ITCZ along the coastline. The ITCZ separates two air masses: the humid air mass of oceanic origin (Monsoon period) and the dry air mass of continental origin, (Harmattan season).

In the coastal area, heavy rains occur generally from May to July (Fig. 2a), but the rainy season begins sometimes in April. During this wet period, humid air goes northward, and rainfall represents 54% of the total for the year. August and September are dry and cool: this is the short dry season. Rains come again in October and November, when humid air goes southward. This short rainy season provides on average 16% of the total rainfall. December to March is the main dry and hot season, with a short cool event (January or February) during the Harmattan period. Rainfall is higher in the western part of the shore (about 1800–2200

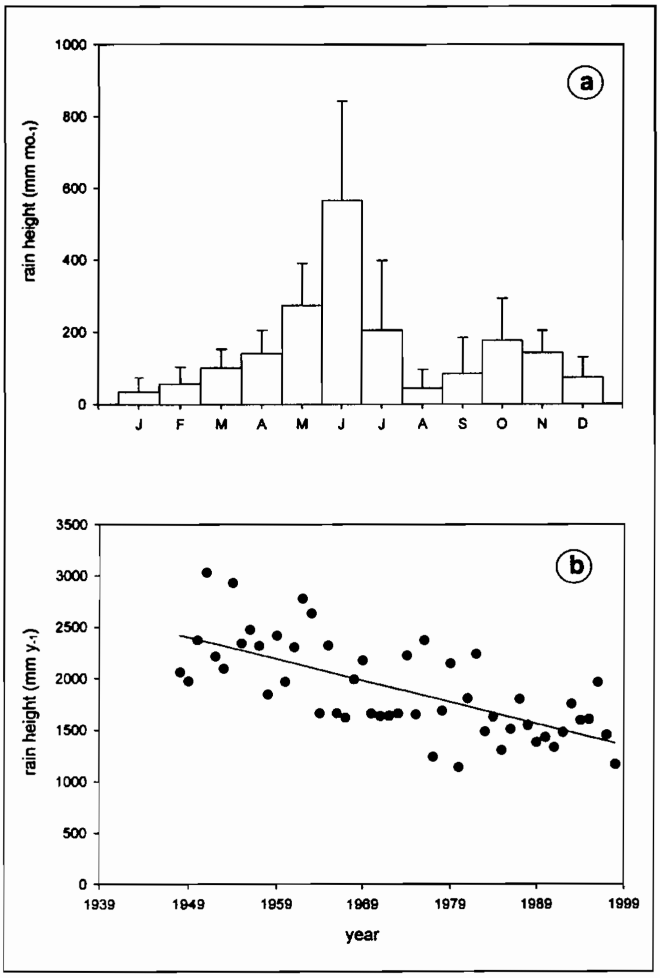

Fig. 2. Rainfall at Abidjan (1948–1998). (a) Monthly rains (average and standard deviation) and (b) annual rain with first-order fit (rain = −20.9 * year +3423, n = 51, r = 0.68).

mm yr^{-1}) than in the central zone, where low values are usually observed (1200–1500 mm yr^{-1}). In the eastern zone, rainfalls range from 1500 to 1800 mm yr^{-1}. Since the 1970s, the intensity of the main rainy season has decreased, while the duration of the short rainy season has been increasing. In recent years, the two seasons showed comparable rainfall. Both for the main rainy season (the lowest values ever recorded in Abidjan) and the short rainy season (heavy rains until December), 1998 was an atypical year. Low rainfall was already observed on occasion in the past decades, but such years, rare in the past, are now more common (Fig. 2b). If the 1950s and 1960s were rather rainy, the decrease observed from the 1970s has now resulted in a large deficit in the coastal area. Now, only the western extremity of the littoral shows annual rainfall higher than 1800 mm. From Sassandra to Grand Lahou, rainfall is lower than 1400 mm yr^{-1}.

Air temperature shows little variation around 26°C, with an average change of 4 and 8°C, respectively, daily and monthly. The sky is often cloudy, particularly during the rainy seasons. Storms are frequent, since the littoral is under the transit line of storms originating from the eastern extremity of the Gulf of Guinea. Tornadoes often occur in March and April.

Effect of Hydroclimatic Variables on the Biological Compartments

Two seasonal factors strongly affect marine and coastal communities living along the shore: floods, enhancing continental influence, and upwellings, enhancing oceanic influence. Freshwater inputs (run-off and river flows) are high from April to July and from October to November. Their consequences on the marine environment are linked to their nature (decrease in salinity), their particulate load (high turbidity) and their dissolved load (increase in nutrient concentrations). Nationally, these effects are limited to the first metres of the water column, and the river plumes in the ocean extend rarely more than a few kilometres southwards. Ocean hydrodynamic factors disrupt the front between continental and marine waters, ensuring rapid mixing. For rivers having their mouth in a lagoon (Bandama, Bia, Tanoé and Comoé), the mixing with brackish water modifies their characteristics. Therefore, the freshwater influence is weakened. Deep seawater inputs extend to the superficial and euphotic cold and nutrient-rich waters, and the whole continental shelf is influenced when upwellings occur. Enrichment is higher in the western zone of the littoral than in the eastern zone and is correlated with upwelling intensity and duration.

In the 0–80 m layer, large seasonal variations govern ecological factors (temperature, salinity, water transparency and nutrient concentrations). Annual cycles are defined from a coastal station in front of Abidjan:

A. After the flood, salinity increase is linked to the reduction of continental outputs (low water for the major rivers, local dry season) and to deep water inputs during the minor cold event.
B. From mid-May to June, salinity decreases when Guinean waters (GW) are present. GW are a combination of oceanic water and freshwater originating from the coastal area of West Africa, carried eastward by the Guinean Current. From October to December, floods induce a marked salinity decrease: the hydrological situation is comparable to the GW sequence, although decrease in salinity is less pronounced.
C. The local rainy season ends when the thermocline reaches the surface. From July to September, upwellings induce sharp water cooling and an increase of surface salinity.

Coastal upwellings establish themselves when surface temperatures fall below 26°C. During this period, surface salinity is high, contrasting with the desalting events linked to the floods. Water transparency decreases in June, when the GW invade the coastal area. Light attenuation is high from June to October (average Secchi depth: 9 m), low from November to May (18 m). The euphotic layer is 20–25 m during the high turbidity period, 35–40 m during the low

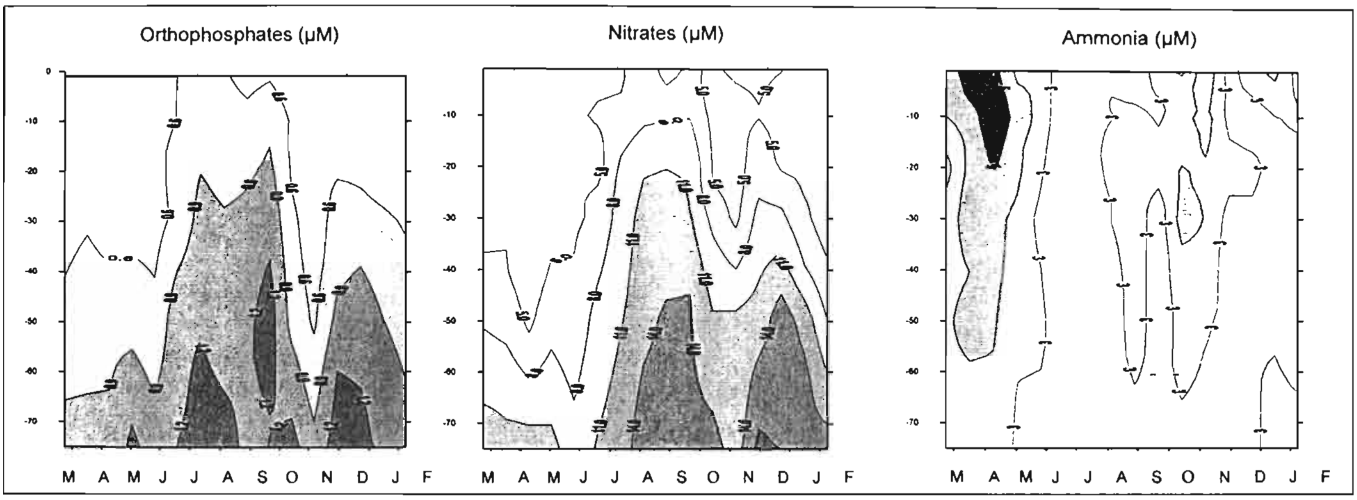

Fig. 3. Contour plot of nutrient annual cycle with depth at the Abidjan coastal station.

turbidity period. Turbidity has decreased between the periods 1966–1971 (average Secchi depth: 10 m, euphotic layer: 27 m) and the 1992–1997 (respective values: 14 m and 36 m). Turbidity is related to local rains, and the decreasing rainfall during the past decades now reduces continental influence. Dam effects complete this phenomenon, since a large part of freshwater particles is trapped in the reservoirs and does not reach the sea. Therefore, the effects of the GW intrusion seem to be less effective today.

Phosphate enrichment of the euphotic layer is clear from mid-June to mid-October (Fig. 3), when the 0.6 μM contour line reaches the surface. Transient incursion of phosphate-rich water above the –30 m level is observed from mid-December to mid-January. Nitrates show the same annual pattern: the average concentration near the bottom (14.4 μM) is four times higher than near the surface (3.7 μM). At these two levels, there is no obvious seasonal cycle, while such a cycle is clear between –20 and –50 m, with a marked concentration increase from mid-June to mid-October. The euphotic layer shows higher concentrations during the upwelling situation than during the sequence under continental influence. Ammonia shows an opposite pattern, with high concentrations from March to May and from October to December. These high values reflect active mineralisation process in the water column that occurs simultaneously with the input of organic matter of continental origin.

THE MAJOR SHALLOW WATER MARINE AND COASTAL HABITATS

The coastline encompasses a variety of coastal habitats including coastal lagoons, estuaries, mangroves, swamps and humid zones. The more characteristic coastal habitats are the lagoon systems. They combine brackish and shallow ecosystems, mangrove and estuaries, in a geographical continuum starting with freshwater conditions and ending at the seashore. Swamps and humid zones cover large areas, mainly along lagoon shores (Fig. 4).

Mangrove

Coastal wetlands are located along the banks of lagoons and estuaries (Nicole et al., 1994). The dominant species are *Rhizophora racemosa*, *Avicennia germinans* and *Conocarpus erectus* (respectively called red, white and grey mangrove). These three species do not coexist in all areas, and *R. racemosa* is usually the main species. It grows well in low salinity zones and it is observed both at the water's edge and further inland. *A. germinans* survives in higher salinity, while *C. erectus*, rather rare, grows at the interface between mangrove and forest. They are accompanied by other

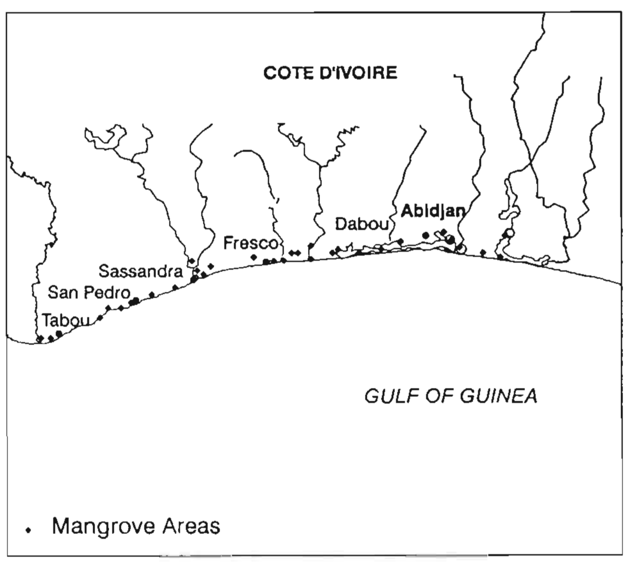

Fig. 4. Mangrove habitats in Côte d'Ivoire.

species, like *Drepanocarpus lunatus, Hibiscus tiliaceus, Dalbergia ecastaphyllum, Acrostichum aureum, Phoenix reclinata, Pandanus candelabrum, Panicum repens* and *Paspalum vaginatum.*

Lagoons

Several shallow systems are observed from Fresco to Assinie (Fig. 5). Most of the scientific efforts have focused on the Ebrié Lagoon. Some studies were conducted on the Aby Lagoon, and the Grand Lahou Lagoon is poorly known. These three systems communicate by artificial canals: Asagny Canal links Grand Lahou and Ebrié lagoons, while Assinie Canal links Ebrié and Aby lagoons. Narrow and shallow, these waterways were once used for transportation but are no longer maintained.

Physical Framework

The Ebrié system (523 km^2, 120 km long, 1–7 km width, average depth 4.8 m, maximum depth 28 m) stretches parallel to the shoreline. Several bays (half-closed or

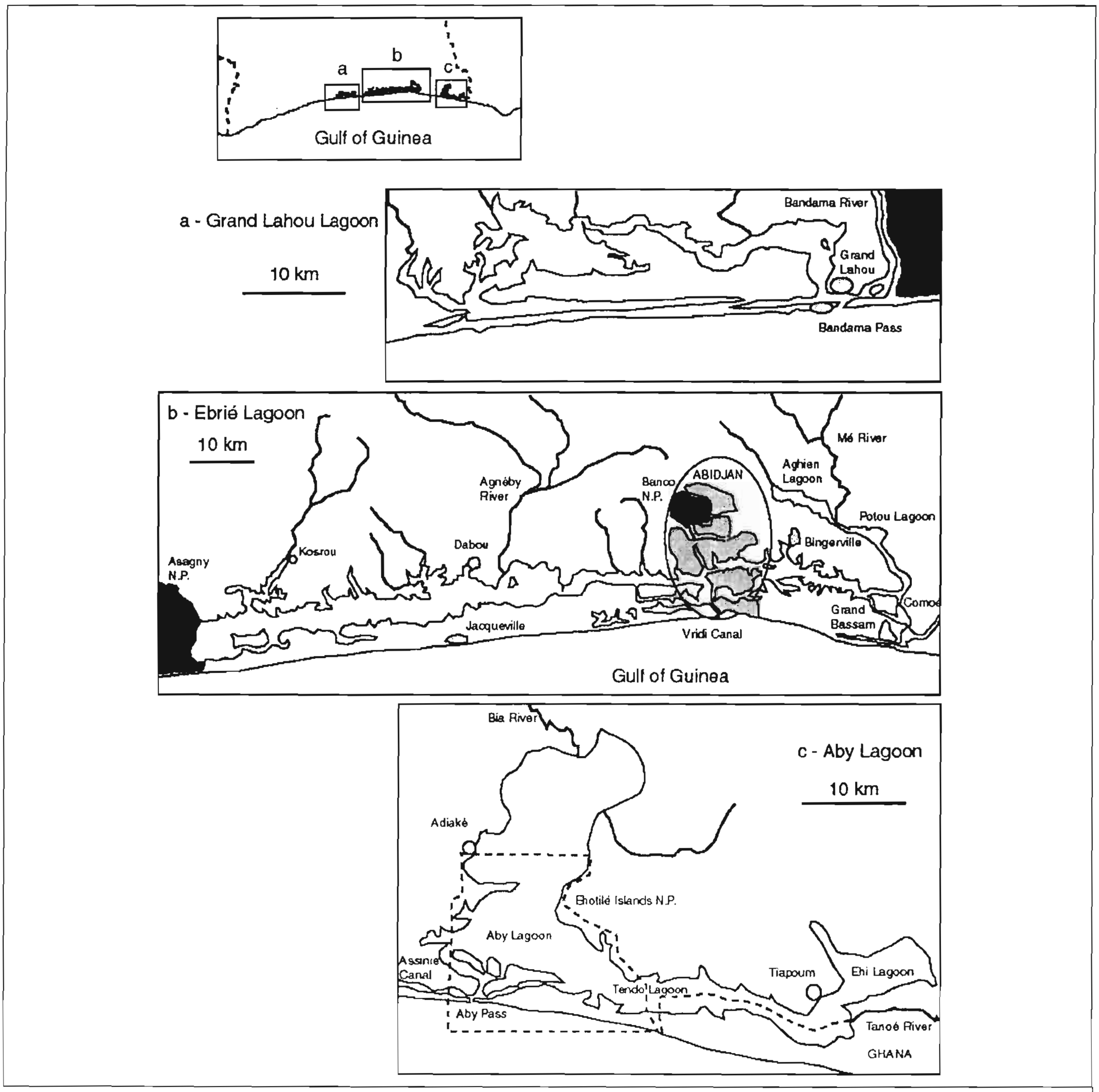

Fig. 5. Sketches of Côte d'Ivoire lagoons.

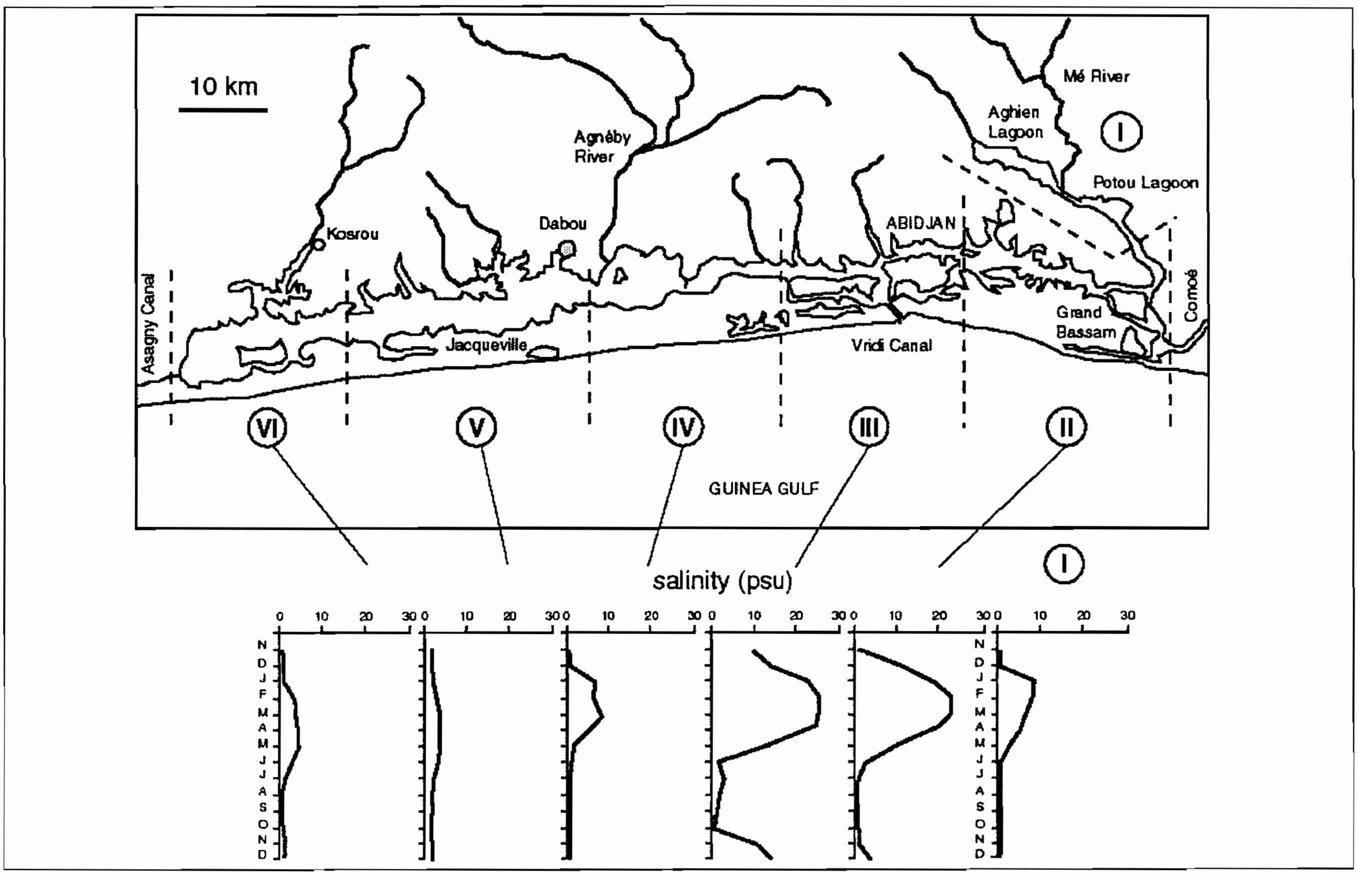

Fig. 6. Zonation in Ebrié lagoon as defined from salinity seasonal variations.

opened perpendicular to the main axis) and secondary basins (Aghien and Potou Lagoons, 43 km²) complete a system with a complex morphology. The artificial Vridi Canal, a unique link between the lagoon and the ocean, allows permanent communication with the Gulf of Guinea and makes Abidjan a secure harbour. Freshwater inputs into the lagoon (rainfall and river flows) range between 2.3 and 22.3×10^9 m³ yr⁻¹. The minimum value was recorded in 1983, in intense drought situation. The average input is estimated to 6.3 10^9 m^3 yr^{-1}. The solid inputs average 0.4 10^6 t yr^{-1}, but the seaward export of the particulate load is estimated to 10% of this figure (Tastet and Guiral, 1994).

Hydrological Zonation

Continental and marine influences are permanently in opposition in the lagoon. From May to December when there is local rainfall and then river floods, the whole lagoon is desalted; the more intense are the annual freshwater inputs, the more lasting will be the phenomenon. From January to April, continental inputs are reduced, but evaporation is at its maximum in a context of dominant oceanic influence. Salinity is highest in the estuarine part of the lagoon. From this seasonal alternation and the morphological structure, a zonation (Fig. 6) has been proposed (Pagès et al., 1979). Zones V and VI are oligohaline, with maximum salinity close to 5 psu and limited amplitude. Zones I and IV are mesohaline (maximum around 9 psu, and minimum close to 0, linked to the flood intensity). Zones II and III are polyhaline. Their highest salinity values are comparable (23 and 27 psu, respectively), but during the flood season, salinity is very low in sector II, and more variable in sector III which is more an estuary under tide influence. Sectors I, V and VI are rather confined, with low turn-over rates, while sectors II, III and IV have high turnover rates. Lagoon waters are characterised by high nutrient concentrations (Dufour, 1994a). In most parts of the north shore, wind-induced resuspension is intense where depths are low, contributing to water turbidity and sediment instability (Arfi et al., 1993a; Arfi and Bouvy, 1995).

Plankton

Phytoplankton biomass and productions are relatively high in areas characterised by high turnover rates, while the more confined areas feature reduced algal activity (Dufour, 1994b). Cyanobacteria, diatoms and chlorophytes prevail in the algal communities (Iltis, 1984). Abidjan's polluted bays show often algal blooms, sometimes characterised by very high numbers of cyanobacteria and euglena (Arfi et al., 1981). Marine or brackish forms characterise the lagoon zooplankton, but the dominant community, with high

Table 2

Main hydrobiological features over the Côte d'Ivoire continental shelf (after Binet, 1979)

	J	J	A	S	O	N	D	J	F	M	A	M
Rainfall	Main rainy season		Short dry season		Short rainy season		Main dry season				Tornadoes	
River regime	Coastal river floods			Main river floods			Low waters					
Upwelling			Main cold events					Short cold events				
Surface temperature		Cold				Warm		Cold		Warm		
Surface salinity	Low	High				Low		High				
Guinea Current thickness (m)	20		10			15		10			30	
GC velocity (kt)	1.4		0.4			0.5		0.5			1.0	
Ivoirian Undercurrent location	Coastal		South								South	
IU speed (kt)	0.8		0.3		0.8		0.6				0.4	
Primary productivity	Moderate		High			Low		Moderate		Low		

Acartia clausi numbers, is not very diverse (Arfi et al., 1987; Pagano and Saint-Jean, 1994). Freshwater and oceanic communities show low numbers. The main assemblage (dominated by cladocerans and cyclopoïds) is observed in both extremities of the lagoon, while the second one (*Lucifer*, calanoids, chaetognaths, salps and medusae) is more diversified and is observed in the estuarine part during high salinity periods. Transition communities show high rotifer numbers.

Benthos

Four main assemblages are defined, all dominated by molluscs (Zabi and Le Lœuff, 1994). In the estuarine area, *Crassostrea gasar* and *Brachyodontes tenuistriatus* are dominant in the upper levels, accompanied by euryhaline crustaceans and polychaetes. *Anadara senilis* and *Tagelus angulatus* prevail in the second assemblage, associated with crustaceans. They share the same environment as the first community, but in less energetic and deeper areas. *Pachymelania aurita* and *Congeria ornata*, seconded by polychaetes dominate the benthos in the eastern part of the lagoon, particularly in low salinity environments. This assemblage covers large areas in the 0.5–2 m strata where microphytobenthos is very abundant (Plante-Cuny, 1977). The fourth assemblage, dominated by *Corbula trigona* and *Iphigenia truncata*, is observed in the whole western part of the lagoon, with very high numbers of *C. trigona*.

Fishes and Fisheries

With 153 species described (Daget and Iltis, 1965; Albaret, 1994), the Ebrié lagoon has relatively high diversity. Morphological complexity, biotope variety and simultaneous presence of marine, brackish and desalted conditions explain this diversity. Several species of continental origin can support moderate salinity variations (*Chrysichtys nigrodigitatus*, *C. maurus*, *C. auratus*, *Clarias ebriensis* and *Hemichromis fasciatus*) but some species are dependant on more specific environments (e.g. *Tilochromis jentinki jentinki*, characteristic of estuarine conditions). Most of them are marine species adapted to brackish situations (*Liza grandisquamis*, *Pomadasys jubelini*, *Ethmalosa fimbriata*, *Trachinotus teraia* and *Pseudolithus elongatus*), which reproduce in the lagoon or which have one development phase in the ocean. Other marine fishes can make transient incursions into the brackish environment. They are accompanied by a wide group of secondary species which have been observed in particular occasions or locations, which contribute to the community diversity. Around 80% of the species are carnivorous, feeding largely on crustaceans, penaeids and mysids, but the more abundant fishes like *E. fimbriata* are adaptable and opportunistic. Fisheries collapsed in the eighties, and the collective fishery has now considerably decreased. Artisanal fishery is now focused on shrimps and *E. fimbriata*. Increasing pollution in the estuarine area (induced by the growing importance of Abidjan sewage and non-point pollution) limits the fisheries in the lagoon.

OFFSHORE SYSTEMS

The annual cycle in offshore areas reflects the same hydrobiological features as those observed in the continental shelf (Table 2); these conditions drive marine community development.

Benthic Assemblages

Benthic assemblages of the continental shelf are characteristic of sandy sediment, and the bottom composition (grain size, organic richness) is the main determinant. From the shoreline to the slope break, four ecological zones have been defined (Le Lœuff and Intès, 1993).

- The infralittoral area lies from the surf zone to around –30 m. Very high hydrological variability is observed (Table 3), with large seasonal variations (at a depth of 10 m, 10°C in temperature, around 3 psu in salinity, but differences are higher at the surface where salinity is close to 7 psu.
- Between –30 and –65 m, the coastal circalittoral zone is permanently under the influence of the thermocline. Seasonal temperature differences are still high (around 10°C), but salinity variations are limited (less than 1.5 psu). During the warm season, temperature exhibits high frequency variability, induced by the vertical movement of the cold layer.
- From –65 m to the slope, the circalittoral zone is hydrologically stable. Diurnal and seasonal changes are limited, owing to the fact that the South Atlantic Central Water is permanently present.
- Below the shelf break there is a biological break-point, but the deeper community remains in hydrological continuity with the circalittoral zone.

From studies conducted from 1966 to 1973, Le Lœuff and Intès (1993) have defined seven benthic assemblages in this continental shelf. Sand and silty sand communities characterise the infralittoral biota. Fifty-three species were found in the first assemblage, forty-five in the second. Sand assemblage (52 species), silty sand (118 species) and sandy silt communities (92 species) are observed in the coastal circalittoral. A coarse and silty sediment assemblage (53 species) is observed in the circalittoral zone. The deep external margin community (21 species) characterises the slope. These assemblages are largely dominated by polychaetes, crustaceans and molluscs, and echinoderms can be sometimes abundant. Carnivorous and detritivorous species are dominant, followed by limivorous and filter-feeders. These communities show analogies with those described in Ghana or in Sierra Leone. In the upper levels (infralittoral and circalittoral), communities show the highest abundance and diversity during the warm season (February to April) and during the main upwelling (August to October). The two rainy seasons are characterised by a decrease in abundance and in diversity.

Table 3

Descriptive statistics for temperature (°C), salinity (psu), and Secchi depth (m) at the coastal station near Abidjan (1992–1997 data). The euphotic depth (m) is calculated after a linear regression between Secchi disk values and light attenuation coefficients ($n = 43, r = 0.84, p < 0.001$, Arfi, unpublished data).

	Min.	25%	Median	75%	Max.
Temperature (–10 m)	18.9	23.2	26.4	27.9	29.9
Salinity (–10 m)	32.59	34.71	35.15	35.54	36.01
Temperature (–50 m)	15.9	18.3	19.8	22.0	26.4
Salinity (–50 m)	34.73	35.69	35.79	35.90	36.15
Secchi depth	4	9	13	18	30
Euphotic depth	14	25	32	39	55

Phytoplankton

Reyssac in the sixties and Dandonneau in the seventies described algal communities and their productivity, summarised in Sevrin-Reyssac (1993). Nutrient inputs during upwelling events allow relatively high algal growth (4–10 10^6 cell l^{-1}, chlorophyll concentrations higher than 1 mg m^{-3}, and average primary productivity of 1 g C m^{-2} d^{-1}). These values usually decrease southward. During the warm season, phytoplankton abundance is low (chlorophyll concentrations lower than 0.2 mg m^{-3}, average primary productivity lower than 0.3 g C m^{-2} d^{-1}), and the same decreasing trend toward the open sea is observed. Dinoflagellates are abundant and diverse in warm conditions (158 species, 65 species of which are *Ceratium*). *Gymnodinium splendens* can induce red tides. Cyanobacteria (*Oscillatoria*) are often present in warm water (>27°C), but disappear rapidly with the intrusion of cold waters. Some diatoms show affinity to warm waters (*Biddulphia sinensis, Hemiaulus membranaceus*), but most of them (several species of the genera *Chaetoceros, Bacteriastrum, Rhizosolenia* and *Coscinodiscus*) bloom in upwelling situation. In these conditions, diversity is low.

Zooplankton

Zooplankton studies, conducted in the seventies (Seguin, 1970; Binet, 1979; Le Borgne and Binet, 1979), are summarised by Binet (1993). Zooplankton communities are perturbed by hydrological instability, such as cold water intrusion during the warm season or periodic freshwater inputs. On the other hand, the main cold event induces a lasting and stable sequence. Zooplankton development is favoured, but the coastal areas are not among the richest: high numbers are often encountered above 60–100 m depths. Open sea assemblages are dominated by copepods, followed by ostracods (though sometimes they can be as abundant as the copepods), appendicularians and chaetognaths. These organisms have their maximum abundance during the main cold event, but they are also well represented during the minor upwelling: their abundance is closely related to the phytoplankton biomass. Salps, pteropods and cladocerans (*Evadne tergestina*) are very abundant during the short cold event. Large crustaceans (*Lucifer faxonii*, mysids, euphausids) and larvae of benthic decapods reach their peak in February, June and from October to December. Most of the species encountered above the continental shelf are eurytherm. During the warm season, carnivorous species dominate the plankton; then, diversity is high but numbers are low. Brackish species (*Acartia clausi, Paracalanus parvus*) are observed in the Gulf of Guinea during the flood season. In upwelling conditions, herbivorous plankton (dominated by *Calanoides carinatus*) show high numbers during the algal bloom, then are replaced by omnivorous species (*Temora turbinata, Centropages chierchiae*).

Pelagic Fisheries

The pelagic ichthyofauna is characterised by marked variability (Marchal, 1993), linked to climatic variation (Cury and Roy, 1987) but also to the fisheries' performance (Ecoutin et al., 1993). Fisheries are based on clupeids (*Sardinella aurita, S. maderensis*), exploited by semi-industrial and by artisanal techniques (Pezennec et al., 1993). The first one, operated mainly from Abidjan, was very active until 1973, when there was a severe decrease in abundance of *S. aurita*. The second one, still important, is operated from several hundreds of canoes, scattered all along the coast. Estimates of annual catches range from 20 to 30,000 metric tons, and Ghana and Côte d'Ivoire share probably the same sardinella stock. Abidjan is also the home of an important tuna fishery with more than 150,000 metric tons processed yearly. But the waters above the continental shelf represent a small part of these total catches (Amon-Kothias and Bard, 1993; Stretta et al., 1993). Three species (*Thunnus albacores, Katsuwonus pelamis* and *Thunnus obesus*) represent the main catches (10,000 to 20,000 metric tons) in the coastal area. Catches are very seasonal, with high values from July to December, probably related to migration patterns.

Demersal Fisheries

A relatively homogeneous community of sciaenids (*Galeoides decadactylus, Pomadasys jubelini, Brachydeuterus auritus, Pseudolithus senegalensis*, and *Cynoglossus canariensis*) is observed above the 10–50 m depth. A sparid community (*Dentex angolensis* and *Pagellus bellotii*), associated with sharks, triglids and groupers, is observed above the 50–120 m depth (Caverivière, 1993). Trawlers and canoes undertake demersal fishing. Total catches range between 5000 and 10,000 metric tons. The bulk of these catches is carried out in the western part of the continental shelf (San Pedro and Sassandra areas). A shrimp fishery is based on *Penaeus notialis*, with an annual catch estimated to 600 metric tons yr^{-1} (Lhomme and Vendeville, 1993). The bulk of that resource is located west of the large river inlets, above the 25–50 m depth. Spawning occurs in November in the ocean, followed by larval development in brackish waters. Migration and recruitment (lasting between 3.5 and 4 months) occur in February in the ocean (Garcia, 1977). Crayfishes are also exploited but the resource is not known.

POPULATION

Of the 12.6 million inhabitants of Côte d'Ivoire, more than 4 million people live in the coastal cities of Abidjan, Grand-Bassam, Jacqueville, Grand-Lahou, Sassandra, San Pedro and Tabou. Coastal population is projected to reach 9 million in 2015, with a growth rate estimated to 4% (national growth rate: 3.7%; average population density: 37.7 inhabitants km^{-2}). Abidjan is presently the economic capital, with about 3.0 million inhabitants. It represents 21% of the total country population and 51% of the total urban population (Table 4).

Before colonisation, indigenous populations (Krou, Nzima, Alladjan, Ebrié, Ahizi, Avikam) populated the coastal zone. Their major activities were centred on small-scale farming and subsistence fisheries using rudimentary tools (Le Lœuff et al., 1993). Development of coastal areas started with colonisation, which introduced profit-earning agriculture (palm tree and coconut), trading and shipping along the coastline. These colonial activities attracted more and more people, especially fishermen from the neighbouring countries (Ghana, Benin, Togo and Liberia, Surgy, 1965) and natives from forest and savanna areas. Trading between European seafarers and Africans took place in several cities (Assinie, Grand-Lahou, Sassandra and Tabou).

The opening of the Vridi Canal in 1950, followed by the construction of Abidjan harbour, gave a major boost to Côte d'Ivoire's economy. Traditional fishing gave place progressively to trawling and tuna fisheries, with the introduction of purse seiners. The number of trawlers rapidly increased from 12 in 1954 to 40 in 1959. Substantial further investments were made, like ice factories, canneries, cold-storage

Table 4

Population trend of the city of Abidjan

Year	Population	Rate
1912	1400	12%
1920	5370	
1934	17,000	
1945	46,000	10%
1950	65,000	
1955	125,000	
1960	180,000	9.3%
1963	254,000	
1970	550,000	11.6%
1975	951,000	
1979	1,415,000	3.8%
1988	1,929,000	
1998	2,500,000	(estimate)

and fish meal industries. Today, Abidjan is the largest tuna and container port of West Africa.

The construction of Abidjan harbour also caused industrial development: more than 60% of the industries of the country are located in the coastal zone or near Abidjan (tourism, oil refinery and offshore oil and gas exploration and exploitation). Abidjan harbour contributes respectively to 96% and 66% of the country's import and export. Its activities represents 90% of the sea traffic of the country and 75% and 40% of that of the neighbouring landlocked countries, Burkina Faso and Mali, respectively. San Pedro harbour, constructed in 1971, represents 10% of Côte d'Ivoire's port activities.

The presence of the country's major industries along the coast has been a factor in the rapid population increase. These industries offer employment opportunities, attracting workers from the landlocked states. Table 4 presents the evolution of Abidjan's population from 1921 to 1994.

RURAL FACTORS

Côte d'Ivoire's economy is based on agriculture, of which coffee, cocoa, palm oil, rubber, bananas, coconut and pineapple productions were considered by the government as the "spear head" of the national economy. Annual production was reported at 868,000 tons for coffee, cocoa and palm oil, 195,000 tons for pineapple, 195,000 tons for bananas, 67,000 tons for rubber, and 55,000 tons for coconut. The rapid population increase and development of agro-industrial activities have exerted a considerable threat on the aquatic environment. Most of the large-scale agricultural plantations located in the coastal zone use large quantities of chemical fertilisers and phytosanitary products, such as insecticides, fungicides, nematocides, raticides and herbicides. Run-off of fertilisers and pesticides from farm lands into rivers and coastal marine ecosystems induces eutrophication and chemical contamination of water and fishes. Organochlorine pesticides have been found in the tissues of several marine fish species (*Pagellus bellotii, Epinephelus aeneus, Cynoglossus canariensis, Pseudotolithus senegalensis, Sphyraena sphyraena* and *Penaeus notialis*).

Many fisheries of the country are artisanal and based mainly in the coastal zone. Population pressures have increased consumption and demands and have led to destructive fishing methods. The use of poisonous substances such as DDT is very common (Marchand and Martin, 1985), inducing mass destruction of fish, coastal environment pollution and health hazard to people.

Although there is a mesh size regulation, lack of enforcement has caused some alteration to the ecological balance of coastal lagoons. Trawling has become dominant in an area formerly dominated by traditional fishermen, in response to increasing demand for fish and fish products. These operations are largely unregulated (or do not conform to existing regulations), with illegal mesh size resulting in destructive fishing, including undersized fish catches.

The open ocean of this region seems yet to be largely unaffected either by man-induced damage or by over-exploitation of natural resources. But living resources are endangered by foreign fleets that "poach" fish from the oceanic area. This fishing pressure has an adverse impact on small-scale operations conducted by local fishing fleets, and artisanal fishermen have noticed a marked decrease in catches of large pelagic and migratory species.

COASTAL EROSION AND LANDFILL

To accommodate the population increase in coastal cities, new housing projects are undertaken, inducing collection of construction materials along the coastline for building purposes. Mining of sand, gravel and other construction materials in the coastal zone is a common practice. Sand and gravel mining from lagoons and from estuaries tends to destroy natural habitats and decrease the amount of fluvial sediment input to the coastline, thereby accelerating shoreline retreat. Sand extraction directly from beaches seriously depletes the sediment pool available and beach retreat is either induced or accelerated.

Increasing awareness of revenue potentially generated by tourism has also led to increased building of tourism facilities on beaches along the coast (Assinie Mafia, Grand-Bassam, Sassandra, San Pedro, Grand-Béréby, etc.). Construction activities in the coastal zone loosen the sediment binding by removing the surface revetments and increasing rainwater runoff. Thus, soil erosion is enhanced. On the other hand, structures constructed on the coast by strengthening soil, may lead to decreased sediment supply to the shoreline. The opposite problem of increased siltation and sediment starvation along the coast depends on the local physiographic conditions.

Besides the increased threat of erosion, mining of construction materials from the coastal zone tends to disrupt fragile ecosystems (e.g., mangroves) and affect their productivity. Several rivers (mainly the Sassandra and Bandama Rivers) are dammed in at least one location. Construction of these dams has resulted in loss of catchment area for sediment, due to the effective entrapment of particles in the reservoirs. Sometimes this loss of sediment input is blamed for coastal erosion that has occurred since the construction of these dams. The severe coastal erosion of Grand-Lahou area is attributed to this process (Abé, 1995). Dam construction has caused the decrease of freshwater input in the lower estuarine reaches of the Bandama River and the alteration of intrusion extent of the estuarine salt wedge inland, with ecological effects on the flora and fauna.

Harbour construction for national and international trade was found to have a direct negative impact on the environment. Erosion at Port-Bouet beach, estimated to be 3 m yr^{-1}, is attributed to the construction of the port of Abidjan (Koffi et al., 1993).

EFFECTS OF URBAN AND INDUSTRIAL ACTIVITIES

Waste Disposal

Although modern industries have had tremendous positive effects on the economy of the coast, they have also largely contributed to the pollution of water bodies along the coast. Near Abidjan, the Ebrié lagoon is heavily polluted by industrial discharges (Broche and Peschet, 1983; Métongo et al., 1993; Dufour et al., 1994). Estimations of pollution loads generated by industries in the Abidjan area have been undertaken (Kouassi et al., 1995). Food manufacturing and textile production are the dominant sources of industrial pollution, producing approximately 85% of the waste volume and 95% of the pollution load. There is no significant production of toxic substances in the area, although pesticide, glue and wood preservative industries have generated some toxic organic effluents.

Domestic effluents include direct sewage and sludge discharges from septic tanks. Only two cities located in the coastal area (Abidjan and San Pedro) have a sewerage system which is even partly effective. The other coastal cities do not yet have either proper drainage facilities or sewage treatment plants. Now, most discharges are made to the waters immediately inshore or to estuaries, or, even worse, to lagoons, most of which have only very poor exchange with the open coastal waters (Métongo et al., 1993).

Dufour and Slepoukha (1975) have provided data on sewage volume discharged to the Ebrié lagoon compared with the volume of receiving waters. In the area immediately around Abidjan, the volume of domestic sewage discharged each year was equivalent to about 18% of the total lagoon volume (estimated to 2.6×10^{9} m^{3}). Domestic sewage accounts for just over half the total effluent volume. For the whole area, the quantity of domestic and industrial wastewater discharged annually is twice the lagoon volume. The Ebrié Lagoon is seasonally subject to marked salinity variations (0–28 psu) and this flushing effect probably helps to minimise impacts. Nevertheless, at least four embayments become regularly anoxic due to the pollution load.

There are few proper facilities to dispose of sewage in many coastal communities, and arrangements for collection of household rubbish are limited or non-existent. As a result, populations use the estuarine and coastal waters or the beaches as dumping places. Some of this rubbish accumulates on the beaches and the scale of the problem is positively correlated with population density. The most commonly encountered forms of litter are plastics, metal cans, and less readily degraded forms of household and industrial refuse.

Toxic wastes are mainly generated by chemical industries. Total production of industrial solid wastes in the coastal area is not known. However, the city of Abidjan concentrates over 60% of the 100,000 metric tons of waste produced by industry, of which one third is eliminated with domestic refuse at the landfill sites. The rest is either recycled or incinerated in the open air (Kouassi et al., 1995).

Oil and Gas Exploration and Exploitation

A major shipping route for oil tankers and other bulk carriers bound for the Middle East to Europe passes offshore from Côte d'Ivoire. The sea-lanes are very wide and the number of accidents involving tankers has been low compared to elsewhere in the world. Nevertheless, beaches are not free of oil pollution. Much of the oil residue found along the shore is due to spills or tank washings from tankers visiting ports in the region, although other sources are important.

Now, exploration, exploitation and refining of oil and gas proceed along the littoral of the country. Although the impacts of these activities are not known, the possibility exists that these activities, while contributing to economic development, routinely introduce a variety of pollutants to the coastal zone and ocean. Pollution includes hydrocarbons from occasional spills, from chronic low-level releases associated with leaking valves, corroded pipelines and ballast water discharges. Construction of pipe networks for hydrocarbon and gas exploitation and transportation, on or near the coast, constitutes visible structural modification of the coastal zone that has adverse effects on coastline migration.

Depletion and Degradation of Coastal Habitats

A major consequence of the population shift toward coastal areas is the increasing degradation rate of coastal habitats. These habitats are lost or damaged by a wide range of activities, including discharge of raw or poorly treated sewage, dredging and filling, discharge of industrial effluents, erosion and overfishing. Specific threats to particular habitats are outlined below.

Lagoons and Estuaries

Lagoons and estuaries are among the most productive of all coastal waters. They serve the special needs of migrating nearshore and oceanic species that require shallow protected habitats for breeding or as sanctuary for their larval stages. Lagoons and estuaries—and the productive source of protein they provide—are threatened by urban encroachment, pollutants of various kinds, siltation and overfishing. Urban development such as that occurring around the Ebrié Lagoon has resulted in habitat (nurseries, sanctuaries, etc.) degradation. Domestic sewage, garbage, and waste fuel are major causes of the decline in productivity of lagoons near urban areas (Albaret and Charles-Dominique, 1982; Kouassi et al., 1990). Industrial effluents, agricultural runoff, and increased sedimentation from poor upstream land and water management schemes are also contributing factors.

For a decade, free floating macrophytes (*Eicchornia crassipes, Pistia stratiotes, Salvinia molesta*) have invaded coastal sites, drifting with freshwater. Most of the large reservoirs are colonised (Ayamé I and II, Taabo and Buyo), as are the rivers. Large rafts of *E. crassipes* and associated species are carried seaward, and then run aground on the beaches. On the large scale at which this happens now in Côte d'Ivoire, these weeds strongly affect water quality, and impede water uses such as transportation, fisheries and other harbour activities.

Mangroves

In most coastal lagoons (especially the Fresco Lagoon), mangroves are severely affected as they are continuously harvested for fuel-wood. Mangroves are also affected by erosion, by changes in salinity and through the construction of canals (Carmouze and Caumette, 1982; Zabi, 1982). These canals were intended for use as transport routes. Their construction had the immediate side effect of increasing suspended solids in the water, which can lead to degradation of benthic fauna. This is followed by more permanent damage as the hydrological regime and salt intrusion alters and spoils banks, and impedes land run-off. Now, water-weeds, like Water Hyacinth (*Eicchornia crassipes*) invade these canals and contribute to their slow filling. Most of the large vertebrates inhabiting the mangrove have almost disappeared, like manatee (*Trichenus senegalensis*), pigmy hippopotamus (*Choeropsis liberiensis*) and crocodiles (*Crocodylus niloticus* and *C. cataphractus*). Forest buffaloes (*Syncerus caffer nanus*) and forest elephants (*Loxodonta africanus cyclotis*) are endangered like several other mammals (otters, chimpanzees) by uncontrolled poaching and deforestation. Mangroves of Côte d'Ivoire have poor bird populations compared to adjacent areas. Developing rice fields could provide additional wetland habitats to waders.

Aquaculture and Fisheries

There are several aquaculture ventures in lagoon regions. There is potentially a risk from sewage or industrial pollution either directly through damage to their stocks or indirectly through adverse effects on the quality of their products (Adingra et al., 1997). Mass fish mortalities occur near urban areas as a result of pollution in the Ebrié Lagoon (Zabi, 1982; Carmouze and Caumette, 1985) while harmful fishing practices in the Aby, Ebrié and Grand-Lahou lagoons are frequent.

Cultural and Historic Sites

Côte d'Ivoire's coastal areas include many cultural and historic sites. Several water bodies serve as objects of worship or are considered to be abodes of gods. Though an intangible resource, such cultural attributes are part of the heritage of riverine populations. This is very important since many inhabitants are followers of traditional religions. The cultural aspects of some of the water bodies are used as a vehicle for encouraging people participation in the management of their resources. Nevertheless, Grand Bassam (classified as an historic site by UNESCO), Assinie and Grand-Lahou are examples of historic cities destined to disappear if nothing is done to stop severe coastal erosion occurring along the eastern part of the coastline.

PROTECTIVE MEASURES

Present measures to control and minimise degradation of marine and coastal environments of Côte d'Ivoire are included in the report on the National Environmental Action Plan (NEAP). The NEAP was elaborated to improve environmental management through strengthening institutional capacity, formulation of standards for environmental quality, development of economic incentives to promote environmental management and establishment of national environmental data management systems. Also envisaged are developments of Integrated Coastal Area Management, biodiversity preservation and integrated management of water resources.

Table 5

International conventions adhered to in the coastal and marine environment

Conventions Place and Adoption Dates	Ratification Date
Convention on International Trade of sites on Endangered Wild Fauna and Flora Species (1975), Washington, 1973	1994
Convention on Biological Diversity, Rio de Janeiro, 1992	1994
International Convention for Prevention of Pollution by Ships (MARPOL) London, 1973	Date to be specified
Convention related to Ozone Layer Depletion: Vienna, 1988; Montreal Protocol, 1987; London Amendment, 1990	1993
Convention on Climate Changes, Rio de Janeiro, 1992	1994
Convention related to Cooperation on Protection and Exploitation of Sea Geographical coastal areas of West and Central African Region (WACAF) Abidjan, 1981	1983
Protocol related to Cooperation on Fight against Pollution in case of Critical Situation	1983
RAMSAR Convention related to Humid Areas of International Importance aiming at Guaranteeing Strengthened Protection of Stay and Nestling Places of some Migratory Species	1993
Bâle Convention on the Control of Transboundary movements of Dangerous Wastes and their Destruction	
Bamako Convention on the Prohibition of Importing to Africa Dangerous Wastes	

Some legislation existed in Côte d'Ivoire but problems arose with implementation and enforcement because many provisions were not specific and penalties were obsolete. Since 1996, a new Outline-Law on the Code of Environment (Le Code de l'Environnement Law No. 96-766 of October 3, 1996) has been voted by the parliament. This new legislation with its pursuance law under preparation, takes into account all environmental aspects including public health, pollution, natural resource management, environmental impact assessment, etc.

Côte d'Ivoire is engaged in many regional initiatives ranging from generally conceived political organisations to highly specialised ones. In the area of marine management and protection, the country has ratified several international conventions (Table 5).

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