Pergamon

Marine Pollution Bulletin, Vol. 36, No. 9, pp. 689–695, 1998

Printed in Great Britain
0025-326X/98 $19.00+0.00

PII: S0025-326X(98)00033-2

Organic and Bacterial Pollution in the Ebrié Lagoon, Côte d'Ivoire

A. A. ADINGRA* and R. ARFI
Centre de Recherches Oceánologiques, BP V 18, Abidjan, Côte d'Ivoire

A systematic study of some pollution indicators [ammonia (NH_4–N), faecal coliforms counts] has been carried out for three years (1993–95) in the urban area of the Ebrié lagoon, evaluating the impact of a sea outfall project. This project, for collecting and forwarding wastewaters of the city of Abidjan to the Atlantic ocean in order to reduce the pollutant load in the lagoon, was initiated in 1994. It failed a few months after the first operation and there is now an overall increase in pollution due to continuous use of the lagoon for dumping domestic as well as industrial and agricultural wastes as a consequence of the malfunctioning of the outfall, which was poorly designed, probably because of insufficient funding. © 1998 Elsevier Science Ltd. All rights reserved

Keywords: pollution; eutrophication; tropical lagoon; sea outfall; faecal coliforms; Atlantic ocean.

The Ebrié lagoon, the largest coastal lagoon in West Africa, covers an area of 566 km^2. This vast body of water (125 km in length and 0.4–7 km in width) is located between 2°50′ and 5°25′ west and is permanently connected to the Atlantic through the Vridi canal (Fig. 1).

The major human uses of the lagoon are fisheries, aquaculture and tourism. The proximity of the city of Abidjan puts considerable pressure on the lagoon. Abidjan is the economic capital and the principal port with an estimated population of 2.3 million, which represents 43% of the population of Côte d'Ivoire. The city hosts almost 70% of the country's industries. Untreated municipal sewage, as well as agricultural and industrial effluents are directly or indirectly discharged into the lagoon (Kouassi *et al.*, 1990; Arfi, 1994). These anthropogenic inputs of pollutants modify the local ecology at the dumping sites (Arfi *et al.*, 1981; Zabi, 1982). They also contribute to the microbial contamination of lagoon waters and thereby increase the public health hazard (Kouassi *et al.*, 1990). Infectious diseases involving bacteria of the genus *Vibrio* (such as *Vibrio cholerae*, *V. parahaemolyticus* and *Aeromonas* sp.) occur endemically or sporadically, among the riverine population of the Ebrié lagoon (Dosso, 1984). Wastes

*Corresponding author.

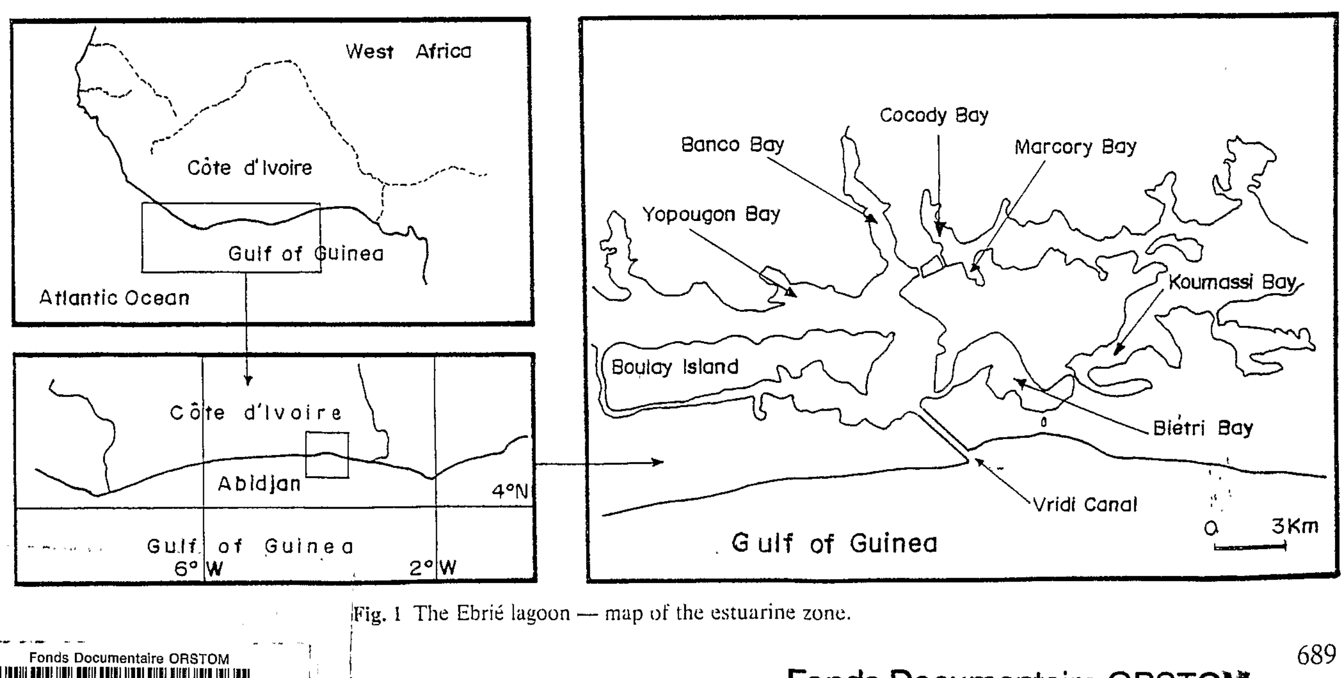

Fig. 1 The Ebrié lagoon — map of the estuarine zone.

may contain chemicals toxic for some species of bacteria, eliminating those bacteria sensitive to the chemicals but resulting in populations of bacteria resistant to the chemicals (Grimes *et al.*, 1986). Thus, an additional public health threat can occur, namely the selection for resistant and potentially virulent strains of allochtonous and autochtonous pathogens.

In 1994, worries about the increasing use of the lagoon for untreated waste disposal stimulated the building of a sewer network for collecting and forwarding wastewaters of the city of Abidjan to the Atlantic in order to reduce the pollutant load in the lagoon. A main sewer (1.2 m dia.) runs south from the district of Abobo to a decantation station and opens into the Atlantic at about 1000 m from the shore, and 20 m below the surface. Due to its favourable tidal and current effects, the ocean affords rapid and effective dilution and dispersion of waste into the seawater. Primary and secondary sewers are connected to the main sewer; they serve the heavily populated areas of Djibi, Bonoumin, Riviéra, Plateau of Banco, Cocody, Koumassi, the residential area of Marcory and the industrial areas of Vridi and the harbour (Fig. 2). At the decantation station, coarse, suspended and floating solids are removed. In mid-1994, when the main sewers was in operation, the primary branches of the Koumassi and of the industrial zone of the port functioned successfully, while those of Cocody and Marcory never succeeded. In December 1994, however, even the working branches were shut down as a result of both a power unit breakdown and complaints from the neighbouring populations of bad smells emanating from the surge shaft at the decantation station. These smells are a result of the long retention time of wastewater in the shaft. Since this shutdown, all the wastewaters are again dumped directly into the lagoon.

This study was undertaken to determine the extent of organic and bacterial pollution of the Ebrié lagoon in 1995 and to compare these results with those of similar studies conducted in 1993 and 1994.

Materials and Methods

Sampling sites

The sampling sites are situated in the urban area of Abidjan (bays of Cocody, Biétri and Marcory) and the site more directly influenced by marine waters (Boulay Island). In each bay two sampling stations were selected, ST1 and ST2 at Cocody, ST3 and ST4 at Marcory, ST5 and ST6 at Boulay and ST7 and ST8 at Biétri (Fig. 2).

Sampling

Surface and bottom water were sampled monthly between January 1993 and February 1996. At each sampling station, water was collected in sterile 250 ml

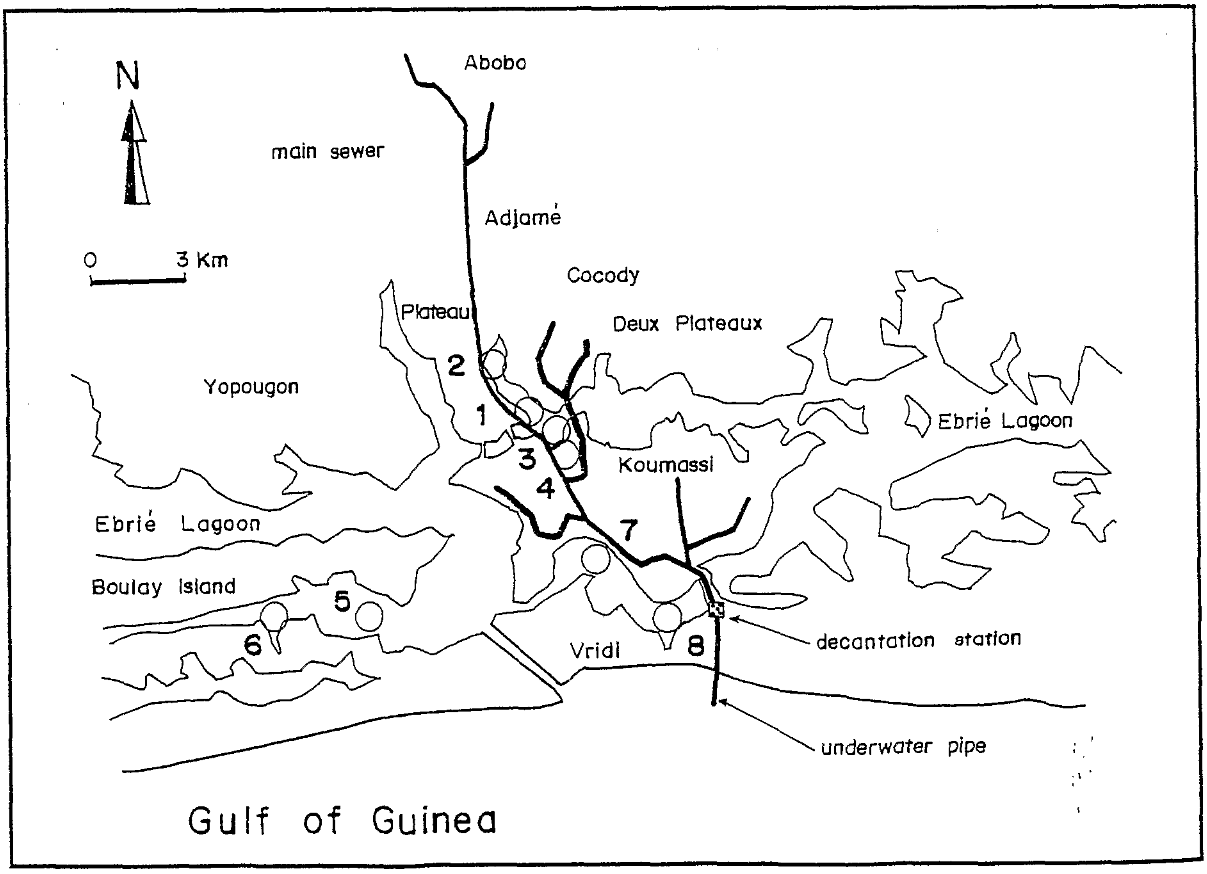

Fig. 2 Draining scheme of the city of Abidjan.

bottles with ground glass stoppers. The samples, kept at 4°C in a cooler box for transportation to the laboratory, were analysed within 2 h of the time of collection.

Chemical and biological parameters analysed

Ammonia was determined using the indophenol blue method of Rosken and Langan modified by Koroleff (1969). The optical density was measured using a Beckman DU spectrophotometer.

Chlorophyll *a* was determined by the fluorometric method after methanol extraction of the phytoplankton retained on Whatman GF/F filters (Lorenzen, 1967).

Total coliforms (TC), faecal coliforms (FC) and *Vibrio paraheamolyticus* (Vph) counts were obtained by the direct plate technique on desoxycholate lactose agar (BioMérieux) and thiosulphate citrate bile-salt sucrose (Difco) respectively. Each water sample was diluted in sterile water with 9% NaCl, plated in duplicate, and incubated at 37°C for TC and Vph and 44.5 ± 0.5°C for FC. Colonies were counted on the dishes after 24 h of incubation. All colony counts were done with the aid of a dissecting microscope at $\times 7$ and $\times 12$ magnification.

Characterization and identification of suspected Vph colonies isolated on thiosulphate citrate bile-salt sucrose were performed using the API 20 E system (Shiaris *et al.*, 1987). Organisms with the following characteristics were called Vph: gram-negative rods, green on thiosulphate citrate bile-salts sucrose agar, oxidase positive, glucose positive for oxidation and fermentation, arginine dihydrolase variable, lysine decarboxylase variable, ornithine decarboxylase variable, urease variable, indole positive, Voges–Proskauer negative, mannitol positive, sucrose negative, arabinose variable, rhamnose negative, sorbitol negative, inositol negative, melibiose negative.

Statistical analysis

Statistical analysis involved non-parametric test (Spearman rank correlation coefficient) and the Student *t*-test.

Results

Table 1 shows the results of the environmental parameters and bacterial contents of the water samples for 1995. The highest annual mean concentrations of NH_4–N were observed in surface waters. These values were higher at the urban bays (ST1–4 and ST7–8) than at Boulay Island (ST5–6, a station directly influenced by clean marine water. Among the urban bays, Cocody was the most polluted (134.7 μmol l^{-1}, SD: 188.9 μmol l^{-1} in surface water and 33.9 μmol l^{-1}, SD: 15.6 μmol l^{-1} in bottom water at site ST2).

The annual mean concentrations of chlorophyll *a* were higher in the bays of Cocody and Biétri than in those of Boulay and Marcory. The Biétri bay was the most eutrophic (83.6 mg l^{-1}, SD: 34.7 mg l^{-1} and 94.7 mg l^{-1}, SD: 52.7 mg l^{-1} in surface water and 38.1 mg l^{-1}, SD 18.0 mg l^{-1}, and 77.9 mg l^{-1}, SD: 45.6 mg l^{-1} in bottom water respectively at sites ST7 and ST8).

The annual mean densities of TC were 10^4 bacteria in 100 ml. FC counts ranged from 10^3 to 10^4 bacteria in 100 ml. The proportion of FC (expressed as a percentage) constituting TC population has been used to indicate the level of pollution (Venkateswaran and Hashimoto, 1988). High percentage densities of FC to TC were observed in the urban bays surface waters compared to the percentage densities from the Boulay station. The annual mean densities for pathogenic bacteria (Vph) in the urban stations and the Boulay station were not significantly different (10^3 bacteria in 100 ml).

TABLE 1

Environmental parameters and bacterial counts in surface (S) and bottom (F) water samples collected between January 1995 and February 1996 in Ebrié lagoon estuarine area.

		ST1		ST2		ST3		ST4		ST5		ST6		ST7		ST8	
		m	s	m	s	m	s	m	s	m	s	m	s	m	s	m	s
Chl *a* (mg l^{-1})	S	14.37	14.06	37.66	30.88	9.80	7.64	12.23	11.90	10.20	6.55	8.48	3.20	83.56	34.72	94.73	52.73
	F	6.72	7.72	21.54	50.83	7.84	8.40	10.48	9.99	2.70	5.07	2.86	3.43	38.13	18.04	77.95	45.47
NH_4–N (μmol l^{-1})	S	17.59	21.02	134.73	188.88	1.57	8.15	29.50	47.89	4.98	2.49	4.22	3.20	12.00	10.51	32.50	32.35
	F	10.89	5.76	33.94	15.62	8.26	4.55	12.15	9.31	3.96	2.29	4.23	3.22	12.96	14.43	21.45	15.99
Vph [log(N/100 ml)]	S	3.24	3.43	3.00	3.26	2.86	2.88	3.09	3.25	3.34	3.67	3.91	4.36	2.28	2.64	3.14	3.19
	F	3.58	3.70	3.25	3.02	3.26	3.40	3.11	3.38	3.10	3.12	3.88	4.19	2.30	2.40	3.06	3.06
CT [log(N/100 ml)]	S	4.56	4.40	4.61	4.66	4.68	4.80	4.82	5.03	3.90	3.88	3.16	3.36	4.59	4.55	4.64	4.71
	F	4.02	4.04	4.60	4.77	4.43	4.54	4.54	4.78	3.06	3.30	2.19	2.26	4.16	4.31	4.36	4.44
CF [log(N/100 ml)]	S	3.39	3.44	4.40	4.73	3.85	4.04	4.16	4.42	2.50	2.62	2.176	2.469	3.997	4.176	4.161	4.31
	F	3.09	3.47	3.85	4.03	3.59	3.75	3.68	3.92	1.00	0.23	0.63	1.06	3.50	3.70	3.23	3.41
CF/CT (%)	S	6.70		62.00		14.68		22.13		3.90		10.00		24.74		33.62	
	F	11.00		17.00		14.68		13.93		0.86		2.74		22.00		7.48	

m = mean;s = SD.

The mean HN_4–N concentrations in surface water at the confined areas ST2 and ST8 were higher than at the areas open to the main body of the lagoon, ST1 and ST7 respectively, in the engulfed bays of Cocody (Student *t*-test, $t = 2.30$, $P < 0.05$) of Biétri (Student *t*-test, $t = 2.20$, $P < 0.05$). The mean chlorophyll *a* concentrations and the mean bacterial concentrations at the confined areas were not significantly different from those of the open areas.

A comparison of the data collected in 1993 and 1994 with those collected in 1995 showed that year to year dynamics of NH_4–N are extremely variable and a general increase in the annual mean concentrations was observed at all the stations except in Marcory (Fig. 3). At Cocody, the most polluted station, the concentrations which were 8 μmol l^{-1} in 1993 were five times higher in 1994 and nine times in 1995. At Biétri, the average concentration was not significantly different in 1993 and 1994 and was twice as high in 1995. At Boulay, where the anthopogenic factor is of little importance, the concentration was considerably lower (2.25 μmol l^{-1}) in 1993, but an increase was notable after two years.

At Biétri, the most eutrophic station, the chlorophyll *a* mean annual concentrations demonstrate a high interannual variability (Fig. 4). The concentrations, which were 32.5 mg l^{-1} in 1993, increased up to 90 mg l^{-1} in 1994 and 1995. At the other stations, the concentrations did not show any significant variation from 1993 to 1995.

The FC counts were not performed in 1994. Therefore, we have compared the results for 1993 and 1995 (Fig. 5). The annual mean FC counts ranged from 10^4 to 10^5 bacteria per 100 ml in 1993 and did not show any significant variation in 1995 at all these stations.

Discussion

Assessment of water quality of the Ebrié lagoon from pollution parameters (NH_4–N concentrations, proportion of FC) showed that the lagoon is severely polluted. The pollution level at the stations studied is dependent upon their hydrological characteristics, the proximity of the discharge points and the importance of the domestic, agricultural and industrial effluent volume discharged into the lagoon (Dufour *et al.*, 1994). Thus, the urban bays, which are heavily impacted by the waste dumping, are severely polluted and eutrophicated (high NH_4–N concentrations, high proportions of FC, and high chlorophyll *a* concentra-

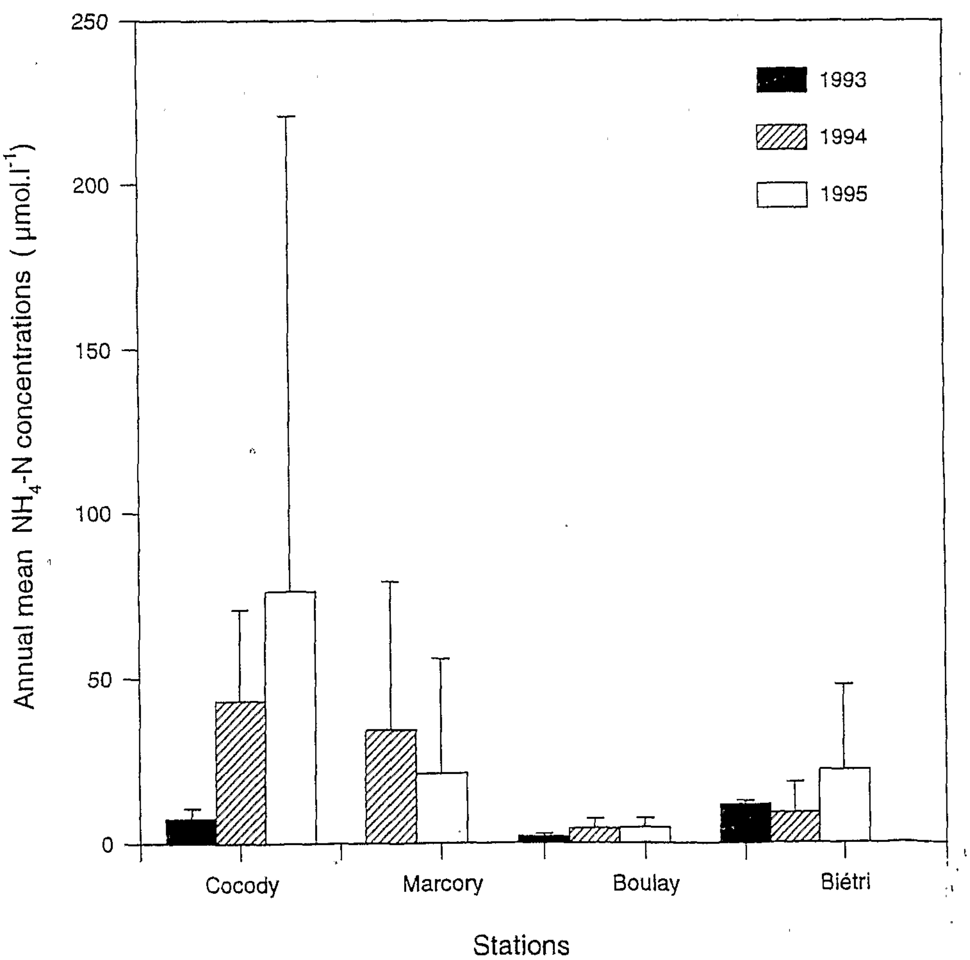

Fig. 3 The annual mean NH_4–N concentrations at the stations studied from 1993 to 1995.

tions). On the other hand, Boulay Island, a station under marine influence, is unpolluted and oligotrophic (low NH_4–N concentrations, low proportions of FC, and low chlorophyll *a* concentrations). The direct discharge of organic wastes into the lagoon contributes to a high nutrient load, enhancing phytoplankton bloom and alterations of community composition. These processes are particularly intense in the bays of Cocody and Biétri because of low water circulation in these areas (Guiral *et al.*, 1991).

In addition, the high organic content of the waste-water provides a suitable substrate for the growth of allochtonous bacteria and autochtonous pathogenic bacteria in these polluted bays (Grimes *et al.*, 1986). This is in agreement with the conclusion of Akpata and Ekundayo (1978) who reported that organic matter supports luxuriant microbial populations. the semi-anoxic conditions brought about by the decomposition of organic matter in the deep lagoon favour the growth of microaerophilic and facultative anaerobic micro-organisms which cause public health hazards (Pagès, 1975).

UNEP/WHO guidelines for bathing water quality have established that acceptable waters should have no more than 90% of the samples tested showing a faecal count greater than 1000/100 ml (Kouassi *et al.*, 1990). Based on this guideline, the lagoon waters are polluted with microbes and there is a considerable risk in bathing in these waters. Fish collected in such waters also have a high probability of becoming contaminated with bacteria.

High incidence rates of pathogenic bacteria (Vph) were noted at both the polluted and unpolluted stations. These bacteria are autochtonous of estuarine waters and their presence is not dependent upon human waste input (Grimes *et al.*, 1986; Shiaris *et al.*, 1987). The high incidence rate of these organisms indicates that they can be used to characterize the bacteriological contamination of these environments and also to estimate the potential danger to human health.

Spatial distribution of the HN_4–N concentrations is significant in the severely polluted bays of low hydro-dynamics, such as the engulfed bays of Cocody and Biétri. In these bays the NH_4–N concentrations are higher in the confined area characterized by low circulation than in the open area. Lemasson *et al.* (1981) reported a renewal rate of 0.20 d^{-1} in the open area and of 0.14 d^{-1} in the confined area in the bay of Biétri. The high concentrations of NH_4–N observed in

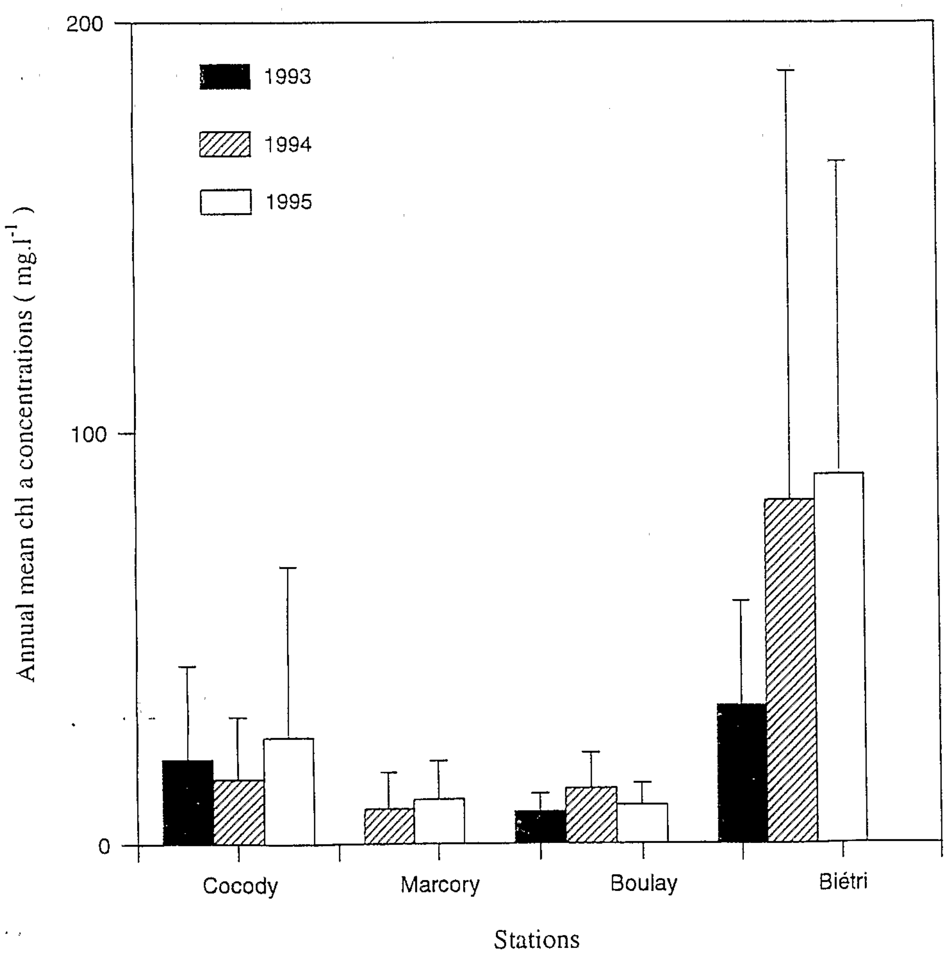

Fig. 4 The annual mean chlorophyll *a* concentrations at the stations studied from 1993 to 1995.

the confined areas probably come from sewage (primary organic pollution), high organic mud deposit in the lagoon (Arfi, 1994) and/or phytoplankton bloom fostered by the effluents (secondary organic pollution, Dufour and Lemasson, 1985).

Conclusion

As the city of Abidjan is still developing, in the absence of a sewage disposal system and without enforcement of regulations to control the pollution sources since the sea outfall project failed, it is likely that the pollution of the Ebrié lagoon will continue to increase. From the present study, evidence abounds that the lagoon ecosystem is severely polluted. The possible negative effects on human health, and the socio-economic consequences of the pollution underline the need for planning of pollution control, from domestic as well as industrial and agricultural sources. New municipal sewage treatment and improved water disposal methods must be developed in order to sustain living resources within the lagoon and coastal waters. One example would be the use of oxidization ponds for pollution abatement from agricultural as well as domestic and industrial sources. Such ecologically engineered systems are often cost effective ways to reduce nutrient and bacterial load to a valuable water recipient (Oragui *et al.*, 1987; Guiral *et al.*, 1991; Jenssen *et al.*, 1994). Such processes could be developed in the Abidjan area where suitable sites are available and primary energy (sun and heat) is very abundant.

Akpata, T. V. I. and Ekundayo, J. A. (1978) Faecal pollution of the Lagos lagoon. *Nigerian Journal of Science* **12**, 40–49.

Arfi, R. (1994) Protection de l'environnement d'Abidjan. Programme de suivi de la qualité des eaux lagunaires et marines. Campagnes 1993. Rapport établi pur la Direction et Contrôle des Grands Travaux. Document CRO Abidjan.

Arfi, R., Dufour, P. and Maurer, D. (1981) Phytoplancton et pollution: premières études en baie de Biétri (Côte d'Ivoire) Traitement mathématique des données. *Océanologica Acta* **4**, 319–329.

Dosso, M. (1984) Ecologie des germes des gastro-entérites infectieuses à Abidjan. Le problème des Vibrionacées. Mémoire d'Etude et de Recherches en Biologie Humaine, Université de Montpellier.

Dufour, P. and Lemasson, L. (1985) Le régime nutritif de la lagune tropicale Ebrié (Côte d'Ivoire). *Océanographie Tropicale* **20**(1), 41–69.

Dufour, P., Kouassi, A. M. and Lamusse, A. (1994) Les pollutions. In *Environnement et resources aquatiques de Côte d'Ivoire*, Vol. II, eds J. R. Durand, P. Dufour, D. Guiral, and S. G.F. Zabi. Editions de l'ORSTOM, Paris.

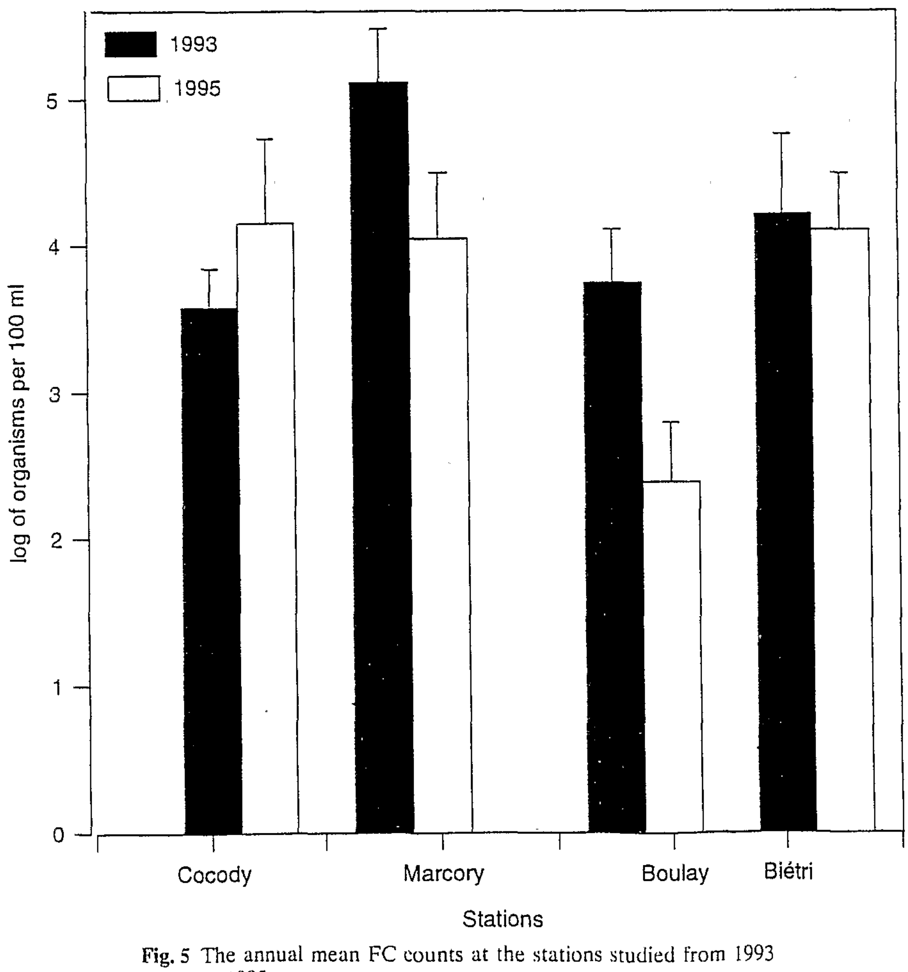

Fig. 5 The annual mean FC counts at the stations studied from 1993 to 1995.

Grimes, D. J., Atwell, W. R., Brayton, R. P., Palmer, M. L., Rollins, M. D., Roszak, B. D., Singleton, L. F., Tamplin, L. M. and Colwell, R. R. (1986) The fate of enteric pathogenic bacteria in estuarine and marine environments. *Microbial Sciences* 3(11), 324–329.

Guiral, D., Kouassi, A. M. and Arfi, R. (1991) Incidence de la modification de la circulation des eaux sur l'hydroclimat et le degré de contamination bactérienne d'un estuaire eutrophe tropical. *Journal Ivoire Océanologie Limnologie Abidjan* I(2), 1–10.

Jenssen, P. D., Maehlum, T., Roseth, R., Braskerud, B., Syversen, N., Njøs, A. and Krogstad, T. (1994) The potential of natural ecosystem self purifying measures for controlling nutrient outputs. *Marine Pollution Bulletin* 29(6-12), 420–425.

Kouassi, A. M., Guiral, D. and Dosso, M. (1990) Variations saisonnières de la contamination microbienne de la zone urbaine d'une lagune tropicale estuarienne Cas de la ville d'Abidjan (Côte d'Ivoire). *Revues Hydrobiologie Tropicale* 23(3), 181–194.

Koroleff, F. (1969) Direct determination of ammonia in natural waters as indophenol blue. ICES, C. M. C:9.

Lemasson, L., Pages, L. and Dufour, P. (1981) Laqune de Bietri: bathymétrie, courants et faux de renouvellement des eaux. *Archives Sci. Cent. Rech. Oleanogr. Abidjan* VII, 1–12.

Lorenzen, C. J. (1967) Determination of chlorophyll and pheopigments: spectrophotometric equations. *Limnol. Oceanogr.* 12, 343–346.

Oragui, I. J., Curtis, P. T., Silva, A. S. and Mara, D. D. (1987) The removal of excreted bacteria and viruses in deep waste stabilization ponds in northeast Brazil. *Water Science Technology* 19, 569–573.

Pagès, J. (1975) Etude de la pollution bactérienne en lagune Ebrié. *Documents Scientifique CRO Abidjan* 9, 97–101.

Shiaris, M. P., Rex, A. C., Pettibone, G. W., Keay, K., Mcmanus, P., Rex, M. A., Ebersole, J. and Gallagher, E. (1987) Distribution of indicator bacteria and *Vibrio parahaemolyticus* in sewage-polluted intertidal sediments. *Applied and Environmental Microbiology* 53, 1756–1761.

Venkateswaean, K. and Hashimoto, H. (1988) Influence of indicator bacteria on the incidence of *Salmonella* in the aquatic environment. *Nippon Suisan Gakkaishi* 45(2), 253–258.

Zabi, S. G. (1982) Les peuplements benthiques lagunaires liés 'a la pollution en zone urbaine d'Abidjan (Côte d'Ivoire). Proceedings of the International Symposium on Coastal Lagoons, SCOR/IABO/UNESCO, 8-14 September 1981, Bordeaux. *Oceanologica Acta* (Special issue), 441–445.