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Impact of treated rubber effluent discharges on shrimp community of a shallow river in south east Côte d'Ivoire

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Abstract
The present study aims to evaluate the impact of rubber effluent on shrimp communities in River Wawa, a shallow river in south east Côte d'Ivoire. Shrimp samples were monthly collected from October 2009 to September 2010 at five sites, using a triangular frame kick net. Physical and chemical parameters were also recorded at each site. The environmental variables varied between sites impacted by rubber effluent and the others. Two species, *Desmocaris trispinosa* (Desmocarididae), and *Macrobrachium thysi* (Palaemonidae) were identified. *D. trispinosa* was found to be most abundant (78.65% recording 619 individuals) and most frequent (%OF=58.33). The rubber effluent discharge in Wawa stream affected shrimp communities in terms of abundance rather than species richness. *M. thysi* preferred high level of dissolved oxygen in water meanwhile; *D. trispinosa* seemed to tolerate water perturbations. The results of the present study combined with those of previous works could contribute to use shrimp as surface water quality bioindicators.

Keywords: Influence, Rubber effluent, Shrimp communities, river Wawa, Côte d'Ivoire.

1. Introduction

During the last century, freshwaters have been severely impacted by human activities [1] through effluent discharges, and by the use of agricultural chemicals [2]. These disturbances can seriously affect the abundance and diversity of living organisms such as macroinvertebrates [3]. Many studies based on macroinvertebrates dynamic were undertaken in south east Côte d'Ivoire to assess the environmental and ecological status of various rivers [4-10]. Among them, few literatures [8, 10] were devoted to shrimp communities in Shallow River. Yet shrimps represent an important food resource and sometimes, the majority of macroinvertebrates biomass in tropical zones [11-12].

The south east region of Côte d'Ivoire has a dense hydrographic network with many shallow rivers subject to disturbances such as effluent discharges and agricultural activities. These streams are also used for domestic purposes (drinking, cooking, bathing, etc.). Therefore, there is a need to preserve these aquatic resources and maintain their biotic integrity. To reach this goal, understand the response of their macroinvertebrate communities to disturbances, is a key in impact assessment, forming the basis of many aquatic biomonitoring methods [13].

The shallow river Wawa receives treated rubber effluent from an agro industrial firm. Effluent from the rubber industry consists of a complex mixture of chemicals, which change the concentration of suspended solids, biological oxygen demand, conductivity, temperature, color and odor of the receiving water bodies [14]. As regards the river Wawa, although the rubber effluent is treated, [15] revealed a modification of water quality, which could have a negative effect on aquatic organisms [16]. Up to now, no study was carried out on Wawa stream to evaluate the impact of such kind of pollution on biological communities, particularly the shrimps.

In order to fill the gap of this ecological information, which is of great interest for aquatic biomonitoring purposes, the present study was proposed. It specifically aims to (i) inventory shrimp species in the river Wawa and (ii) investigate the relationship between shrimp distribution and water quality.

2. Materials and methods

2.1. Study area and sampling sites

The study was carried out on River Wawa, a first order stream of approximately 3 km, located in rubber tree plantations in Alépé, South East Côte d'Ivoire (5°29' N and 3°31' W). The corresponding area is characterized by four seasons: a long rainy season (April to July), a short dry season (August to September), a short rainy season (October to November), and a long dry season (December to March). It belongs to the subequatorial climate characterized by an average annual temperature ranged from 25 °C to 33 °C. The rainfall varied between 1 400 to 2500 mm/year and an annual rate of humidity about 80 to 90% [17].

Five sampling sites were surveyed during this study (Figure 1). Four sites located on the receiving stream, were chosen considering the discharge point of the industrial effluents: two upstream (U1, U2) as non-subject to effluent and two others downstream (D1, D2). Moreover, one site on the tributary of river Wawa was also retained. Surveys were monthly conducted from October 2009 to September 2010 at each sampling site.

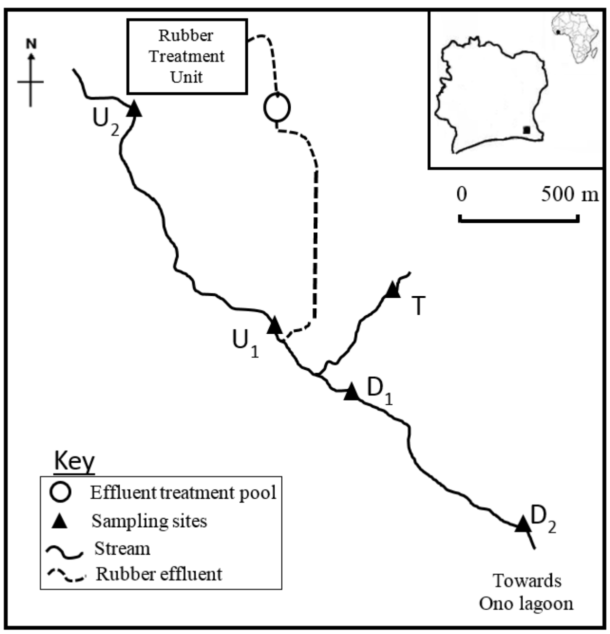

Fig 1: Sampling sites location. U1: Upstream site 1; U2: Upstream site 2; D1: Downstream site 1, D2: Downstream site 2; T: site on the tributary of river Wawa.

2.2. Environmental conditions

At each site, physical and chemical parameters were measured, and water samples for laboratory analyses were collected prior to shrimp sampling.

Water temperature and pH, conductivity, dissolved oxygen, and turbidity were measured *in situ* with a pH-meter (WTW pH 3110) including a thermometer, a conductivity-meter (WTW COND 3110), an oxygen-meter (WTW Oxi 3205), and a turbidimeter (AQUATLYTIC PCH 37164), respectively. Water depth and width were measured using a tape measure and a stick marked at 1 cm intervals.

Current velocity was measured as implemented by [8] and it was taken in mid-channel on five occasions by timing a floating object over a five meter stretch.

For determination of nitrate, nitrite, ammonia, phosphate, chemical oxygen demand (COD), water samples were collected in 500 ml polyethylene bottle, placed in an ice chest at 4 °C and analyzed in the laboratory by means of a spectrophotometer (HACH DR/2010).

2.3. Shrimp collection and identification

Shrimps were monthly collected from October 2009 to September 2010 using a triangular frame kick net (25 x 25 x 25 cm, and 250 µm mesh size). Sampling was conducted during five minutes at each sampling site and within approximately 10 m portion of the site. The material retained in the net was transferred and kept in plastic bottles containing a 70% ethanol solution. The shrimps caught were identified under a microscope following [18-20].

2.4. Data analysis

The occurrence percentage (%OF) was calculated using the following formula:

%OF = (Ni/Nts) × 100,

With Ni = number of samples containing a given species i, and Nts = total number of samples collected.

The %OF was used to classify species following [21]: %OF>50: very frequent species; 25 <%OF ≤ 50: common species; %OF ≤ 25: rare species.

Before performing comparison analyses, data normality was checked using Shapiro-Wilk test. Given the biotic data distribution does not follow normal distribution ($P<0.05$), then Kruskal–Wallis and Mann–Whitney tests were performed to compare data between sampling sites. ANOVA (Analysis of Variance) was carried out on the environmental variables. A significance level of $P < 0.05$ was considered.

Hierarchical Ascending Classification (AHC) based on Euclidean distance and Ward's algorithm was performed to cluster sampling stations according to their water physico-chemical parameters.

Species abundance in relation to environmental variables was analyzed using Spearman's correlation test [22]. The ReDundancy Analysis (RDA) method was used to detect patterns of species association related to environmental variables [23]. Environmental variables and shrimp data were log10(x+1) transformed prior to analysis. Monte Carlo permutations (500) were done so as to identify a subset of measured environmental variables which exerted significant and independent influences on shrimp distribution at $P<0.05$. In the ordination diagram environmental factors is indicated by the relative length of vectors, i.e. the longer the vector, the greater the influence on species distribution [23]. RDA was performed using Canoco for Windows Version 4.5.6 [24] whereas R version 3.1.1 computer package was used for the other tests.

3. Results

3.1. Environmental conditions

The mean values of environmental variables are shown in table I. The data revealed significant variation in mean values of all environmental variables between sites except temperature, and ammonium. Water temperature varied from 25.43 °C (U1 and U2) to 25.80 °C (D1), and ammonium from 0.78 mg/L (D2) to 1.54 mg/L (D1). Overall, with the exception of dissolved oxygen and width of the bed, the highest values of the other environmental parameters were observed in the sites receiving the industrial effluents (D1 and D2). The values of dissolved oxygen were higher (3.40 – 5.31 mg/L) in the sites situated in upstream of the discharge point of the industrial effluents (U1 and U2). The Wawa River was wider at sites U1 (5.85 m) and

D1 (5.63 m) compared to the others (1.74 – 3.26 m). Concerning conductivity, phosphate (PO_4^{3-}) and chemical oxygen demand (COD), the values recorded after the discharge point of the industrial effluents were at least twice as those obtained in other sites. The Wawa river was globally acid with pH values varying from 5.95 (D1) to 4.93 (T). The site T presented the same trends with U2 for nitrate (higher values) and turbidity (lower values). This site showed intermediary values for pH, conductivity, and dissolved oxygen.

Table 1: Environmental parameters measured at the sampling sites (U1: Upstream site 1; U2: Upstream site 2; D1: Downstream site 1, D2: Downstream site 2; T: site on river Wawa tributary).

Parameters	**Sampling sites**					**F-ratio**	***p*-value**
	U2	**U1**	**D1**	**D2**	**T**		
pH	5.31±0.38	5.48±0.32	5.95±0.28	5.90±0.27	4.93±0.47	17.65	<0.001
Cond (µs/cm)	26.38±0.89	31.49±2.09	64.63±15.70	58.08±12.65	48.16±0.76	39.77	<0.001
DO mg/L	5.30±0.70	3.40±0.47	3.14±0.45	2.68±0.53	3.07±0.44	41.68	<0.001
Temp (°C)	25.43±0.35	25.43±0.69	25.80±0.28	25.78±0.38	25.60±0.15	2.23	NS
Turb (NTU)	7.05±5.08	10.03±6.27	16.07±6.94	10.90±4.11	5.62±4.99	6.34	<0.001
Depth (m)	0.30±0.07	0.40±0.18	0.61±0.12	0.26±0.09	0.30±0.06	18.47	<0.001
Width (m)	3.04±0.21	5.85±0.70	5.63±1.24	3.26±1.30	1.74±0.27	49.18	<0.001
Vel (m/s)	0.32±0.05	0.35±0.15	0.41±0.09	0.32±0.12	0.21±0.05	6.86	<0.001
NO_2^- (mg/L)	0.00±0.00	0.00±0.00	0.61±0.02	0.16±0.09	0.00±0.00	4.38	<0.05
NO_3^- (mg/L)	6.67±5.28	2.00±0.64	3.42±2.65	9.71±7.92	7.54±6.01	3.48	<0.05
NH_4^+ (mg/L)	1.25±0.47	1.26±0.98	1.54±0.56	0.78±0.41	1.33±1.21	0.63	NS
PO_4^{3-} (mg/L)	0.12±0.02	0.11±0.03	3.23±1.95	1.63±0.84	0.12±0.07	15.46	<0.001
COD (mg/L)	15.36±9.93	20.44±15.6	39.48±9.28	40.52±23.27	35.82±30.37	2.42	<0.001

DO: Dissolved Oxygen; Cond: Conductivity; Turb: Turbidity; Vel: Velocity; Temp: Temperature; NS: Non-Significant relationship

The Hierarchical Ascending Classification performed to cluster sampling sites allowed to distinguish 3 groups of sites (Figure 2). The group I was composed of upstream sites (U1 and U2). The group II was represented by one site, located on the tributary of river Wawa (T) and the group III gathering the downstream sites (D1 and D2). The site T is closer to the downstream sites rather than upstream sites.

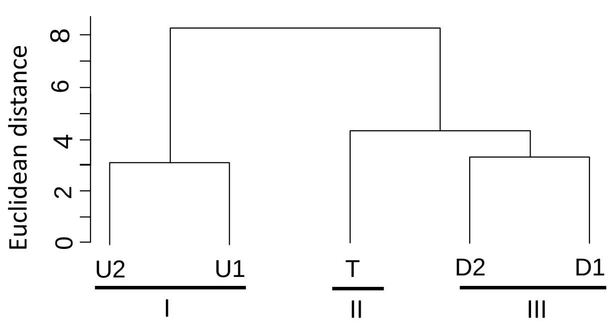

Fig 2: Hierarchical Ascending Classification based on environmental variables, presenting the grouping of sampling sites

3.2. Composition and distribution of shrimp species

During this study, two shrimp species, *Desmocaris trispinosa* (Desmocarididae), and *Macrobrachium thysi* (Palaemonidae) were collected. From all the investigated sites, *D. trispinosa* appeared very frequent (%OF=58.33) and *M. thysi* was common (%OF=41.66). Considering each site, *D. trispinosa* was rare (%OF=25) at U2 while *M thysi* appeared very frequent (%OF=92). At site U1 the two species were rare with the same occurrence percentage (%OF=8). *M. thysi* remained a rare species at D1 (%OF=8) and D2 (%OF=8) while *D. trispinosa* appeared very frequent (D1: %OF=83; D2: %OF=100). On the tributary (T), *D. trispinosa* (%OF=75) as well as *M. thysi* (%OF=92) are very frequent.

A total of 787 shrimp individuals were collected over all the sampling campaigns. In terms of abundance, *D. trispinosa* with 78.65% of the shrimp collected was the most abundant species.

The distribution of the shrimp abundance is presented in figure 3. *D. trispinosa* was more abundant at the downstream sites (D1 and D2) than upstream sites (Mann–Whitney test: $p<0.05$). In contrary, *M. thysi* was more abundant at U2, an upstream site, than other sites (Mann–Whitney test: $p<0.05$). The lowest abundance of both *D. trispinosa* and *M. thysi* was found at U1. Only one individual of each species was recorded at this site. The site T was the only one which held both *D. trispinosa* and *M. thysi* in an important quantity. The abundance of *Desmocaris trispinosa* at this site is higher than in upstream sites.

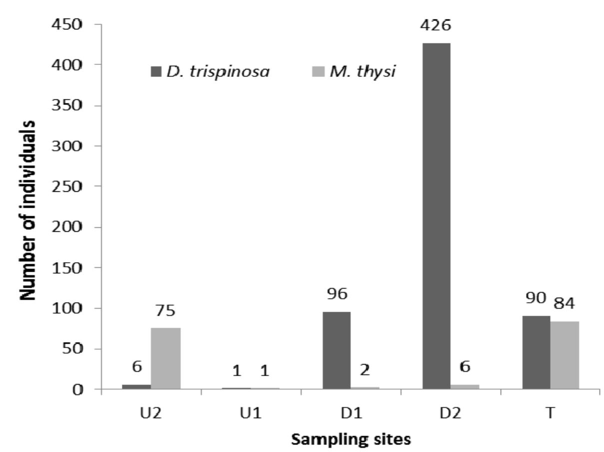

Fig 3: Number of shrimp individuals caught at the sampling sites

3.3. Correlations between shrimp community and environmental variables

The analysis of Spearman correlation (Table II) indicated that the influence of some environmental variables is opposite from one species to another. The parameters which influenced significantly both *D. trispinosa* and *M. thysi* are pH, conductivity, dissolved oxygen, nitrite, and phosphates. However, temperature, nitrates and COD influenced positively *D. trispinosa* only. On another hand, turbidity, width and current velocity influenced negatively *M. thysi* abundance. Depth and ammonia had no effect on the abundance of both species.

Table 2: Results of Spearman correlation analysis between shrimp abundances and environmental variables.

Environmental variables	Shrimp species			
	D. trispinosa		*M. thysi*	
	p-value	Rs	*p-value*	Rs
pH	<0.001	0.396	<0.001	-0.550
Conductivity	<0.001	0.587	<0.05	-0.388
Dissolved Oxygen	<0.001	-0.438	<0.05	0.314
Temperature	<0.05	0.389	NS	-0.098
Turbidity	NS	0.079	<0.001	-0.404
Depth	NS	-0.139	<0.05	-0.280
Width	NS	-0.239	<0.001	-0.616
Velocity	NS	-0.045	<0.001	-0.436
NO_2^-	<0.001	0.325	<0.001	-0.574
NO_3^-	<0.001	0.412	NS	0.129
NH_4^+	NS	-0.044	NS	-0.109
PO_4^{3-}	<0.05	0.358	<0.001	-0.449
COD	<0.05	0.365	NS	-0.078

Rs: Spearman correlation coefficient; NS: Non-Significant relationship

Results of Redundancy Analysis (RDA) showed that the correlation between environmental factors and shrimp species was perfectly explained by the first two axes (100% of the total variance). Globally, axis I opposed the downstream D2 to the upstream sites (U1, U2) (Figure 4). Considering this axis the sampling sites T and D1 are in an intermediary position. *M. thysi* abundance was strongly correlated with high level of dissolved oxygen in water. This species was found to be negatively affected by high values of conductivity, pH, phosphates, and turbidity. *D. trispinosa* was more abundant in sites where conductivity, pH, nitrates, and COD were higher. Unkike *M. thysi*, *D. trispinosa* was tolerant to low oxygen level in water.

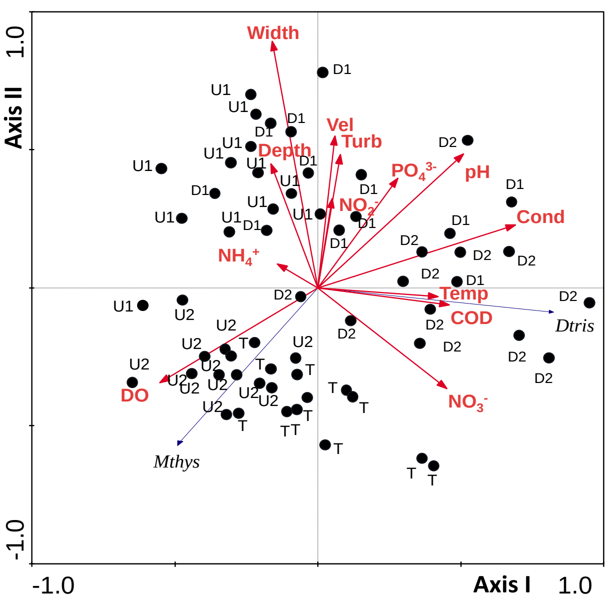

Fig 4: Redundancy analysis triplots showing relationships between shrimp species, environmental variables and sampling sites. DO: Dissolved Oxygen; Cond: Conductivity; Turb: Turbidity; Vel: Velocity

4. Discussion

The results of the present study showed that the sampling sites are characterized by variation in physical and chemical variables due to the effluent discharge. Indeed, the downstream sites, impacted, held high values of conductivity, turbidity, nitrites, phosphates and COD. However, the dissolved oxygen concentration is higher in the upstream sites while the site on the tributary recorded intermediary value. This depletion of oxygen content from upstream to downstream site is indicative of organic loads which required high level of oxygen for chemical oxidation and decomposition [15]. The waters of the five investigated sites are generally acidic. This fact is certainly not due to rubber effluent but to the substrate as argued by [25]. These authors stated that the physical and chemical characteristics of a river are strongly linked to the nature of soil basin. In the South-East region of Côte d'Ivoire soils are acidic [26]. Site T, non-impacted by the rubber effluent is closer to the downstream sites in terms of physical and chemical characteristics according to the HAC. This site may be subject to other sources of disturbance undetected throughout the present study. Deeper investigations should be done to clearly explain this similarity. However that may be, any change either through natural or anthropogenic sources influences water quality as well as aquatic organisms [27].

This survey revealed that only two shrimp species are present in the shallow river Wawa: *D. trispinosa* and *M. thysi*. This species richness is similar of that obtained in other studies carried out in shallow rivers. In fact, [8] recorded three species (*M. thysi*, *M. dux*, and *D. trispinosa*) in Banco River. Furthermore, [10] captured three species (*M. thysi*, *M. raridens*, and *D. trispinosa*) in four shallow rivers (Ehania, Bodoua, Boulo 1 and Boulo 2) in southeast of Côte d'Ivoire. The low shrimp species diversity may be attributed to the streams size [8, 10]. In contrast, this species richness was very low in comparison to those of other relatively large rivers in Côte d'Ivoire. Indeed, seven, nine and 10 species were found in the Bia [28], Boubo [6] and Mé [7] rivers, respectively. The ability of bigger rivers to support higher species diversity is explained by the fact that they have large range of various microhabitats being able to host more species [29].

The common species of the works in shallow rivers were *Desmocaris trispinosa* and *Macrobrachium thysi*, suggesting that these species are characteristics of these types of environment in south east Côte d'Ivoire and could be used as bioindicators.

In all case, the weak specific richness may not be due to disturbance of environment. It is constant along the river, from upstream sites to downstream sites. This is contrary to the findings of [10] who noticed a decrease of specific richness in rivers receiving palm oil in their catchment.

In total, 787 shrimp individuals were collected. Globally, *D. trispinosa* was the most abundant (78.65%) and very frequent species (%OF=58.33) than *M. thysi*. This result is consistent with [8, 10]. It can be assumed that *D. trispinosa* is a prolific species in the shallow river in south east Côte d'Ivoire. In shallow rivers of a periurban forest of Douala (Cameroon), this species was abundant (36.07%) and very frequent (FO=61.54%) after the Atyid shrimp *Caridina africana* [30].

Among the sites located on the receiving stream, U1 recorded the fewer shrimp abundance with only one individual per species. Yet, as an upstream site, U1 is normally not subject to rubber effluent discharge. Hence, this few abundance may have another explanation than rubber effluent pollution. A valuable reason could be anthropogenic pressure exerts by population on shrimp community. They fish shrimp with net in this portion of the river for their food needs.

D. trispinosa was more abundant and very frequent at the downstream sites where pH, conductivity, turbidity, nitrites, phosphates and COD are higher than upstream sites. In the contrary, *M. thysi* was less abundant and rare at the downstream sites than the upstream sites except U1. Globally, the two species abundance evolves following two opposite gradients in river Wawa. As for the tributary, the site T appeared very particular not only by its physicochemical characteristics, but also through its shrimp abundance. The HAC analysis clearly showed that site T represented a distinguished group. Considering the shrimp composition, site T is the unique one where *D. trispinosa* and *M. thysi* were simultaneously collected in large number. It can be assumed from these results that site T offered good environmental conditions for both species. Similar results have been observed by [10] on a tributary of Boulo river receiving palm oil mill effluents.

The correlation analysis (spearman correlation and RDA) showed that *D. trispinosa* abundance increased with increasing pH, conductivity, temperature, nitrites, nitrates, phosphates and COD but with low dissolved oxygen content. The tolerance of *D. trispinosa* was reported by [8, 10]. In addition, [31] reported that this species seems to tolerate unfavourable conditions such as low dissolved oxygen and significant organic matter. However, [30] stated that *D. trispinosa* requires good water quality.

As far as *M. thysi* is concerned, good oxygen level was favorable to its proliferation. This species abundance decreased with increasing pH, conductivity, turbidity, river width, nitrites and phosphates content. The same trends were observed for *M. thysi* in the Banco River [8] and four rivers in southeast of Côte d'Ivoire [10]. These observations suggested that *M. thysi* is less tolerant to environmental disturbances.

Several studies have shown that species richness, abundance and distribution of benthic macroinvertebrate's assemblages are extremely influenced by physicochemical water quality [32-34].

In this study, rubber effluent modified water quality precisely in the downstream sites and set a distribution of shrimp in which *M. thysi* decreased after the point of reject and *D. trispinosa* increased after the point of dejection. It would be possible, due to water self-epuration capacity described by [15], to find a proliferation of *M. thysi* far away in downstream area. The findings of this survey combined with others carried out in shallow rivers in south east Cote d'Ivoire [6-8, 10, 28], could contribute to the use of shrimp as bio indicators. For instance *M. thysi* could be used to characterize clean water and *D. trispinosa* for stressed sites.

5. Conclusion

In this study two shrimp species (*M. thysi* and *D. trispinosa*) were collected in the Wawa stream. The rubber effluent discharge in Wawa stream affected shrimp communities in terms of abundance rather than species richness. *M. thysi* are abundant upstream the point of effluent dejection whereas *D. trispinosa* are abundant after this point. Their abundance is strongly influenced by water pH, conductivity, dissolved oxygen, nitrite, and phosphates.

The results of the present study combined with those of previous works could contribute to use shrimp as surface water quality bioindicators. However, further investigation should be performed about all macroinvertebrates of river Wawa, to understand the impact of rubber effluent on this important biotic component. Such a study will contribute to the development of biotic index for shallow rivers in south east Côte d'Ivoire.

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