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CODEN: IAASCA **ORIGINAL ARTICLE**

A First Systematic Survey of Southeastern Ivory Coast Diatoms (Bacillariophyta)

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ABSTRACT
The composition of diatom communities developing in southeastern rivers of Ivory Coast: Soumié, Eholié, Ehania and Noé, were studied from July, 2003 to March, 2005. Samples were taken upstream and downstream on each river from the pelagic zone and from different substrates (leaf, wood and stone). One hundred and forty-five species and/or varieties were inventoried, belonging to 44 genera, with a predominance of pinnates, which represent 94.5% of the taxa. The most dominant genera were: Navicula (15 taxa), Eunotia (14), Nitzschia (13) and Pinnularia (12). The highest species richness was recorded in the upstream part of the Ehania river (92 taxa), and the lowest in the downstream section of the same river (73 taxa). Eighty-one of the 145 taxa were registered for the first time for Ivory Coast. The most frequent taxa encountered in the 4 rivers were Planothidium lanceolatum, Eunotia incisa, Nitzschia palea, Gyrosigma acuminatum, Navicula menisculus and Ulnaria biceps. Eight taxa could not be identified to the species level. Four inventoried species, (Gomphonema parvulum, Gyrosigma acuminatum, Nitzschia palea, and Ulnaria biceps) were common to all the studied habitats. The present study has the aim to develop a diatom database for the Ivory Coast.
Keywords*: Bacillariophyta, diatoms, Ivory Coast, taxonomic richness, tropical rivers.*

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INTRODUCTION

Tropical waters are increasingly degraded by significant climate variability and anthropogenic pressures (drinking water, fisheries, aquaculture, irrigation, uncontrolled urbanization, uncontrolled landfills, agriculture, agro-industries, etc.). Faced with these threats and in order to preserve the quality and biodiversity of aquatic ecosystems, several countries have succeeded in improving water quality significantly. This was possible due to scientific studies of the physical, chemical and biological functioning of these ecosystems [1]. But also by the development of several biological indexes, including those based on diatoms, such as the Slâdecek Index (SLA) [2], Diatomic Generic Index (SDI) [3] Diatomic Practice Index (IDP) [4], Diatomic Trophic Index (TDI) [5], and The IBD (Biological Diatom Index) ([6], [7]). Of all these indexes, only the IBD was standardized (NF T90-354 2000). Both in research and in practice, diatoms have been used since the beginning of the century to assess water quality ([8]; [9]). Indeed, the composition and distribution of diatoms reflect the influence of environmental conditions on their populations. Diatom populations and communities have the advantage of integrating environmental conditions, which have a direct effect on species survival [10]. Some key trends emerged very early in salinity system reconstruction, as well as reconstruction of pH (acidification) and assessment of organic pollution (pollution from sewage). More recently, scientists have used diatoms to determine impacts on trophic levels (eutrophication). In Europe, North America and Japan, diatoms are used for routine studies [4] or for specific requirements [8]. In Africa, the use of these indexes is rare. But, the work of [11] in Morocco should be mentioned. For the Ivory Coast, so far these indexes to assess water quality have not yet to be used. In addition, diatom data is fragmentary and more focused on backwaters ([12], [13], [14],

[15]). Diatoms studies for the Léraba and Bagoé rivers ([16], [17]) and Bia and Agnébi [15] have been researched, but diatoms from small coastal streams have been ignored. Coastal streams are increasingly being disturbed due to diversification of activities in their catchment (rural settlements, agriculture and livestock). This is particularly true of Soumié, Eholié, Ehania and Noé rivers, distinguished by having very few houses along their course, but they are areas of important agricultural activities. Characterization of the current diatom communities is necessary for the identification of potential disruptions. This preliminary work aims at the study of diatom composition and distribution in upstream and downstream sections of the four mentioned rivers.

Material and methods

Study area: The south-eastern Ivory Coast has a relatively dense hydrographic network consisting of several coastal rivers, which include Soumié, Eholié, Ehania and Noé (Figure 1). Two stations on each river were chosen on the basis of their accessibility and hydrological zonation. Stations surveyed in waters' course are surrounded by plains except station E1 (Akakro), occurring in a U shaped valley and Eh1 (Af enou) in an asymmetrical valley. Stations are characterized by the presence of cocoa plantations and forest. Stations Eh1 (Af enou), N1 (M'Possa) and N2 (Noé) are located near a village. Aquatic vegetation (*Nymphaea lotus* L. and *Eichhornia crassipes* (Mart.) Solms) was only present at Af enou, covering 30% of water.

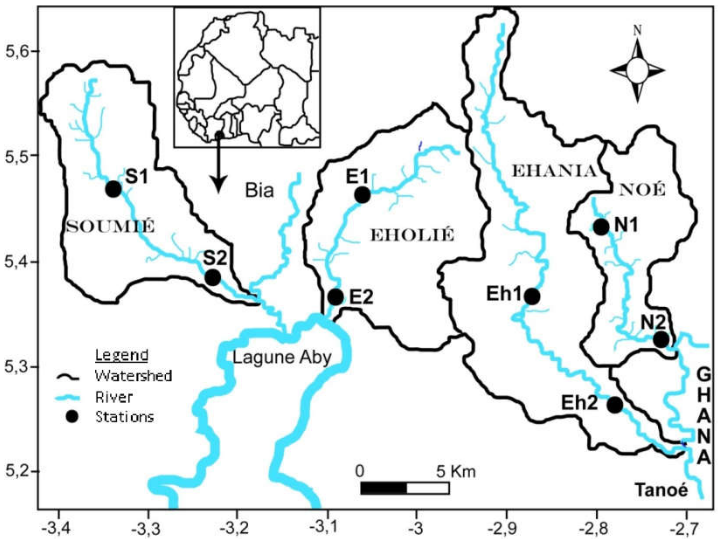

Figure 1: Location of rivers and sampling stations (modi ed by author) S = Soumie, E = Eholie, Eh = Ehania, N = Noe, 1 = upstream, 2 = downstream.

Measuring of abiotic parameters: Eight sampling periods (ie 32 samples in total) were carried out from July, 2003 to March, 2005, covering the four climatic seasons: the long dry season (March and December), the long rainy season (June and July), the short dry season (August and September) and the short rainy season (October and November); Two samplings were carried out for each season. Physical and chemical parameters were measured using various devices. A GPS MLR SP12X was used to reference geographical location of the different stations. Conductivity was measured using a HACH conductivity type, model 44600. A pH meter WTW was used to measure pH and water temperature. Measurement of dissolved oxygen was taken using a pulse type WTW. A Secchi disc enabled the determination of transparency. Five floats, a stopwatch and a tape of measurement were used to determine water velocity. Conductivity, pH, temperature, dissolved oxygen, transparency and water velocity measurements were taken *in situ*. A sample of surface water was taken and kept in a one liter bottle at 4°C to determine nitrate concentration. In the laboratory, nitrate concentrations were determined according to standard T90-110 AFNOR.

Sampling, observation and identification of diatoms: Planktonic diatoms were collected using a plankton net (10 µm mesh), while periphytic diatoms were removed from macrophytes, woods and stones using a toothbrush. Samples were stored in 30 ml bottle. Diatoms were oxidized by boiling in technical nitric acid following the [18] method. Cleaned diatoms were then mounted between slides and cover slides with Naphrax (refraction index: 1.73). Observation of taxa was performed using a Trinocular microscope type Olympus BX40 to magnification x1000. Identi cation of taxa was made to the species level or infraspecies level using various works (keys and/or description) such as those of [19], [20], [21], [22], [12], [13], [23], [24], [25], [26], [27], [18] and [28].

Data analyses Occurence is a method that provides information on the environmental preferences (habitat) of a species. It reflects the number of times species *i* appears in samples [29]. This number is expressed as a percentage of the total number of records and provides information on frequently encountered in a river system without any indication of the quantitative importance of the species encountered ([30]; [31]):

$$F = \frac{F_i \times 100}{F_t}$$

Fi = number of records containing species i; Ft = total number of surveys.

Depending on the value of F, three species groups are distinguished [29]:

- Constant species (F ≥ 50%);
- Accessories species (25% ≤ F <50%);
- Rares species (F <25%).

For the physical and chemical data, nonparametric tests (Kruskal–Wallis test and Mann–Whitney Utest) were used to measure the degree of environmental parameter variation between stations and saisons. Tests were signi cant at $p < 0.05$.

Correspondence analyses (CA) highlight successive uncorrelated factors. This analysis summarizes the common response of a group of species are common factors [32]. CA was performed on the species composition to analyze the spatial distribution of the taxa and to group the stations related to their sampling substrates and according to their floristic similarities. Taxa with a relative abundance greater than 1% in at least one sample were used in the subsequent analyses to minimize the influence of rare taxa. This analysis was performed using the R software version 2.0.1 [33] fitted with the package ade 4 [34].

RESULTS

Physical-chemical variables: Spatial and temporal variations of physical and chemical parameters of water in the four rivers surveyed are showed in [35]. There was very little seasonal variation of all parameters ($p > 0.05$). The values of pH indicate a low changes from upstream to downstream and from one season to another. These values are circumneutral (6.6–7.5, $p > 0.05$). In all rivers, dissolved oxygen concentrations (3.6–9.8 mg l^{-1}, $p < 0.05$) were significantly higher downstream than upstream. Low variation ($p > 0.05$) from one station to another and from one season to the next was observed for flow velocity. The highest rates (0.7 m s^{-1}) were recorded during the short rainy season and the lowest rates (0.1 m s^{-1}) during the high dry season. Nitrate concentrations were lower upstream (1–1.5 mg l^{-1}) relative to the downstream stations (2.2–3.4 mg l^{-1}). High concentrations of nitrates are noted during the high rainy season at all stations except the downstream of Noe River (high dry season). As for conductivity, values obtained are higher upstream (60.8–68 µS cm^{-1}) except for the Eholié River where the variation is lower (52.3 and 60 µS cm^{-1}) from upstream to downstream.

Diatoms composition: One hundred and forty-five (145) species and infraspecific categories belonging to 44 genera were identified (Table 1). Pinnates represented 94.5% of the species while only 5.5% were centrics. The genera *Navicula* (15 taxa), *Eunotia* (14 taxa), *Nitzschia* (13 taxa) and *Pinnularia* (12 taxa) have more species. Eighty-one (81) taxa were registered for the first time in Côte d'Ivoire, relates to other study in the country. The distribution of diatoms in different stations is fairly homogeneous. The number of taxa ranges from 70 in Eh2 station (downstream of the river Ehania) to 86 in E2 station (downstream of the river Eholié). Taxa constantly encountered in the rivers were *Planothidium comperei* C.E.Wetzel, N'Guessan & Tison Rosebery, *Eunotia incisa* W.Greg., *Nitzschia palea* (Kütz.) W.Sm., *Gyrosigma acuminatum* (Kütz.) Rabenh., *Navicula menisculus* Schum. and *Ulnaria biceps* (Kütz.) Lange-Bert. Four species (*Gomphonema parvulum* Kütz., *Gyrosigma acuminatum* (Kütz.) Rabenh., *Nitzschia palea* (Kütz.) W.Sm. and *Ulnaria biceps* (Kütz.) Lange-Bert.) were found in all habitats in rivers studied.

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Table 1: List of diatoms of this study (highlighted in grey: taxa encountered for the first time in Ivory Coast).

		Soumié		Eholié		Ehania		Noé	
	Codes	S1	S2	E1	E2	Eh1	Eh2	N1	N2
Centrales									
Aulacoseiraambigua (Grun.) Simonsen	Aamb	0	1	1	1	1	0	1	0
Aulacoseiragranulata (Ehrenb.) Simonsen	Augr	1	1	1	1	1	1	1	1
Cyclostephanosdamasii(Raben.) Stoer. &Kans.	Cyda	1	1	0	1	1	1	1	1
*Cyclotellameneghiniana*Kütz.	Cmen	1	0	1	1	1	1	1	1
Cyclotellaocellata Pant.	Coce	1	1	0	0	1	0	0	1
Orthoseiraroseana (Raben.) O'Meara	Orro	1	0	1	1	1	1	1	0
Terpsinöeamericana (Bail.) Ralfs	Team	0	0	0	0	1	0	0	0
*Terpsinöemusica*Ehrenb.	Temu	1	0	1	1	0	1	1	1
Pinnates									
Achnanthesinflata (Kütz.) Grunow	Acin	1	1	1	1	0	1	0	1
Achnanthidiumcatenatum(J.Bílý&Marvan) Lange-Bert.	Adct	1	0	1	1	1	0	1	0
Achnanthidiumexiguum(Grunow) Czarn.	Adeg	1	0	1	1	0	0	1	1
Achnanthidiumminutissimum (Kütz.) Czarn.	Admi	1	0	0	0	1	1	0	0
*Amphoracommutata*Grunow	Amco	1	1	1	1	1	1	1	1
*Amphora*sp.	Amsp	0	0	1	0	0	0	0	0
*Bacillariaparadoxa*J.F.Gmel.	Bpar	1	1	1	1	1	1	1	1
Caloneisbacillum(Grunow) Cleve	Cbac	0	0	1	0	0	0	0	0
*Caloneis*aff. *schroederi* Hust.	Csch	0	0	0	0	1	0	0	0
*Caloneisleptosoma*Hust.	Clep	0	0	1	0	0	0	0	0
Caloneis sp.	Csp	0	0	1	0	0	0	0	0
Capartogramma crucicula (Grunow ex Cleve) Ross	Cacr	1	1	1	1	1	1	1	1
Cavinulacocconeiformis(W.Greg. ex Grev.) D.G.Mann& Stickle	Caco	0	0	1	1	1	0	0	1
Cocconeiseuglypta(Geitler) Lange-Bert.	Ceug	1	1	1	1	1	1	1	1
Cocconeisshroederii Foged	Cshr	1	1	1	1	1	1	1	1
*Cocconeis*sp.	Cosp	0	0	0	1	0	0	1	0
Craticulacuspidata(Kütz.) D.G.Mann	Ccuh	1	0	0	1	1	0	0	1
*Cymbella*aff. *tumida*(Bréb.) Van Heurck	Ctum	0	0	1	1	1	1	0	0
*Cymbella*sp.	Cysp	1	0	0	0	0	0	0	0
*Diadesmisconfervacea*Kütz.	Dcof	1	0	0	0	0	0	1	1
Diadesmis contenta (Grunow ex Van Heurck) D.G.Mann	Dcot	1	1	1	1	1	1	1	1
Diploneisoblongella(Nägeli) A.Cleve	Dobl	1	1	1	1	1	1	1	1
Diploneisovalis(Hilse) A.Cleve	Dova	0	1	1	1	1	0	1	0
Encyonemaminutum(Hilse) D.G.Mann	Enmi	1	1	0	0	0	0	1	0
Encyonemasilesiacum (Bleisch) D.G.Mann	Esba	1	1	1	1	1	1	1	1
Eolimna minima (Grunow) Lange-Bert.	Eomi	0	0	0	1	0	0	0	1
*Eunotia*aff. *sudetica*O.Müll.	Esud	0	1	0	1	0	0	1	0
Eunotiabinularis (Ehrenb.) Mills	Ebil	1	1	0	0	1	0	0	1
*Eunotiacamelus*Ehrenb.	Euca	0	0	0	1	0	0	0	0
Eunotiaexigua (Bréb.) Raben.	Eexi	1	1	0	0	1	1	0	0
Eunotiafaba(Ehrenb.) Kütz.	Efab	0	1	0	0	0	0	0	0
*Eunotiaincisa*W.Greg.	Einc	1	1	1	0	1	0	0	0
Eunotia minor (Kütz.) Grunow	Emin	0	1	0	0	0	0	0	0
*Eunotiamonodon*Ehrenb.	Emon	0	1	1	1	0	0	0	0
Eunotiapectinalis(Kütz) Raben.	Epec	1	1	0	1	1	1	1	1
Eunotiapectinalis(Kütz) Raben. var. *ventricosa*Grunow	Epvt	0	0	0	0	0	1	0	0
*Eunotiapraerupta*Ehrenb.	Epra	0	0	0	1	0	1	0	0
*Eunotiapraerupta*var.*bidens*(Ehrenb.) Grunow	Eprb	0	0	0	1	0	1	0	0
*Eunotiarabenhorstii*var. *monodon*Grunow	Eura	1	1	1	1	1	1	1	1
Eunotiasoleirolii (Kütz.) Raben.	Esol	1	1	0	1	1	1	1	0
*Eunotiatschirchiana*O.Müll.	Etsh	1	1	0	1	1	1	1	1

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Fallaciaauriculata(Hust.) D.G.Mann	Faur	0	0	1	0	0	0	0	0
Fallaciamonoculata(Hust.) D.G.Mann	Fmoc	0	0	0	1	0	0	0	0
Fallaciatenera(Hust.) D.G.Mann	Ftnr	0	0	1	0	0	0	0	0
*Fragilariabidens*Heib.	Fbid	1	0	1	1	0	0	1	1
Frustulia crassinervia (Bréb.) Lange-Bert. & Krammer	Fcrs	1	1	1	1	1	1	1	1
Frustuliarhomboides (Ehrenb.) De Toni	Frho	1	1	0	1	1	1	0	1
Frustuliavulgaris(Thwaites) De Toni	Fvul	0	1	1	1	1	1	1	1
*Geissleria*sp.	Gesp	1	0	1	1	1	0	1	1
*Gomphonema affine*Kütz.	Gaff	1	1	1	0	1	0	1	1
Gomphonemaangustatum (Kütz.) Raben.	Gant	0	0	0	1	0	0	0	0
Gomphonema augur var. *turris* (Ehrenb.) Lange-Bert.	Gaug	0	0	1	0	0	0	0	1
*Gomphonema gracile*Ehrenb.	Ggra	1	1	1	1	1	1	1	1
*Gomphonemaparvulum*Kütz.	Gpar	1	1	1	1	1	1	1	1
Gomphospheniapfannkucheae(Cholnoky) Lange-Bert.	Gpfa	0	0	0	0	0	0	0	1
Gyrosigmaacuminatum (Kütz.) Rabenh.	Gyac	1	1	1	1	1	1	1	1
Gyrosigmanodiferum (Grunow) Reimer	Gnod	1	1	1	0	1	1	1	1
*Hantzschia*sp.	Hasp	1	1	1	1	1	1	1	1
Hantzschiavirgata(Roper) Grunow	Havi	0	1	1	1	0	1	1	1
*Hippodonta*aff.*avittata*(Cholnoky) Lange-Bert.	Havt	1	1	1	1	1	1	1	1
*Luticola*aff. *lagerheimii*(Cleve) D.G.Mann	Lucla	0	0	0	1	1	1	0	0
Luticolacohnii (Hilse) D.G.Mann	Lcoh	1	1	0	0	0	0	0	0
Luticolagoeppertiana (Bleisch) D.G.Mann	Lgoe	1	1	1	1	1	1	0	1
Luticola muticoides (Hust.) D.G.Mann	Lmut	1	1	1	1	1	1	1	1
*Navicula angusta*Grunow	Naan	1	0	0	0	1	0	0	0
*Navicula arvensis*Hust.	Narv	0	1	1	1	1	0	1	1
*Navicula cryptocephala*Kütz.	Ncry	0	1	0	1	1	1	1	1
Navicula cryptotenella Lange-Bert.	Ncte	1	1	0	0	1	0	0	0
Navicula heimansioides Lange-Bert.	Nhmd	1	1	1	1	1	1	1	1
Navicula heufleriana (Grunow) Cleve	Nhtg	1	0	0	0	0	0	0	0
*Navicula menisculus*Schum.	Name	0	0	1	1	1	0	1	1
*Navicula radiosa*Kütz.	Nrad	1	1	0	1	1	1	1	0
*Navicula rostellata*Kütz.	Nros	1	1	0	0	0	1	1	1
*Naviculaschroeteri*F.Meister	Nshr	1	1	1	1	1	1	1	1
Navicula sp1	Nasp1	0	1	0	0	0	0	0	1
Navicula sp2	Nasp2	0	0	1	0	0	0	1	0
Navicula viridula var. *germainii* (J.H.Wallace) Lange-Bert.	Nvge	0	0	1	1	1	1	1	0
Neidium affine f. *undulata*Hust.	Neau	0	1	0	0	1	0	0	0
*Neidium affine*var. *amphirhynchus* (Ehrenb.) Cleve	Neaa	0	1	0	0	0	0	0	0
Neidiumampliatum (Ehrenb.) Krammer	Neam	1	1	1	1	1	1	1	1
Neidiumapiculatum Reimer	Neap	0	0	0	1	1	0	1	0
Neidiumiridis (Ehrenb.) Cleve	Neir	1	1	0	0	0	0	0	1
*Nitzschiaamphibia*Grunow	Namp	1	0	0	0	1	0	0	0
*Nitzschia*aff. *frustulum* (Kütz.) Grun.	Nftu	0	1	1	1	1	1	1	1
*Nitzschiaclausii*Hantzch	Ncla	1	0	0	1	1	0	1	1
Nitzschiadissipata (Kütz.) Grunow	Ndsp	1	1	1	1	1	1	1	1
*Nitzschiaflexa*Schum.	Nifl	1	0	1	1	1	1	1	0
Nitzschia intermedia Hantzsch ex Cleve & Grunow	Nint	1	0	0	0	1	1	0	1
Nitzschia*nana*Grunow	Nnan	1	1	1	0	1	1	0	1
*Nitzschiaoliffii*Hust.	Noli	0	0	0	0	1	0	0	1
Nitzschia palea (Kütz.) W.Sm.	Npal	1	1	1	1	1	1	1	1
Nitzschia recta Hantzsch ex Raben.	Nrec	0	0	0	0	0	1	0	0
*Nitzschiasubacicularis*Hust.	Nsua	0	1	0	0	0	0	0	0
*Nitzschiasvedstrupii*Foged	Nsve	1	1	1	1	1	1	1	1
Nitzschiaterrestris (J.B.Petersen) Hust.	Nter	0	0	0	1	1	0	0	0
Pinnulariaacrosphaeria (Bréb.) Raben.	Pacr	1	1	0	1	0	0	0	0
Pinnularia biceps f. *petersenii* R.Ross.	Pbip	1	0	1	0	0	0	1	0

Pinnulariabrauniana(Grunow) Studnicka	Pbrn	1	1	1	1	1	1	1	1
*Pinnulariadivergens*W.Sm.	Pdiv	1	1	0	1	0	1	0	1
*Pinnulariaeburnea*Zanon	Pebu	1	0	1	0	0	0	1	0
Pinnulariagibba(Ehrenb.) Ehrenb.	Pgib	1	1	0	1	1	1	1	1
*Pinnulariagibba*var. *sancta*(Kütz.) Raben.	Pgsa	1	1	0	0	0	0	0	0
Pinnulariamicrostauron (Ehrenb.) Cleve	Pmic	0	1	0	1	1	0	1	0
Pinnulariapolyonca(Bréb.) W.Sm.	Ppol	0	0	1	0	0	0	0	0
Pinnularia sp.	Pisp	0	0	0	0	1	0	1	0
*Pinnulariasubcapitata*W.Greg.	Psca	0	1	1	1	0	1	1	1
*Pinnulariatropica*Hust.	Ptro	1	0	1	0	0	0	0	0
*Placoneis*aff. *densa* (Hust.) Lange-Bert.	Plde	1	1	1	1	1	0	1	1
Placoneiselginensis (Greg.) Cox	Pelg	1	0	0	0	1	0	1	1
Placoneishambergii (Hust.) Bruder	Pham	0	0	0	0	1	0	0	0
Placoneisperlatoides(Hust.) Coste & al.	Pper	1	0	0	0	1	1	1	1
Placoneis sp1	Plsp1	1	1	1	1	1	1	0	1
Placoneis sp2	Plsp2	1	1	0	0	0	1	0	0
Placoneissurinamensis(Cleve) Metzeltin& Lange-Bert.	Psur	1	1	1	1	1	1	0	1
PlanothidiumcompereiC.E.Wetzel, N'Guessan&Tison Rosebery	Pcom	1	1	1	1	1	1	1	1
Planothidiumrostratum(Østrup) Lange-Bert.	Ptro	1	1	1	1	1	1	1	1
Rhopalodiagibberula(Ehrenb.) O.Müll.	Rgbl	1	1	1	1	1	0	1	1
Sellaphorabacillum(Ehrenb.) D.G.Mann	Seba	0	0	1	1	1	1	1	1
Sellaphoranyassensis(O.Müll.) D.G.Mann	Snya	0	1	1	1	1	1	1	1
Sellaphorapseudopupula(Krasske) Lange-Bert.	Seps	1	1	1	1	1	1	1	1
Sellaphorapupula (Kütz.) Mereschk.	Spup	1	0	0	0	0	0	0	1
Seminavisstrigosa (Hust.) Danielidis&Econ.-Amilli	Smst	1	1	1	1	1	1	1	1
*Stauroneisanceps*Ehrenb.	Stan	1	1	1	1	1	1	0	1
Stauroneislegumen (Ehrenb.) Kütz.	Stle	1	0	0	0	0	0	0	0
Stauroneisphoenicenteron(Nitzsch) Ehrenb.	Spho	0	1	1	1	1	0	1	0
Stauroneissmithii var. *incisa*Pant.	Stsmi	0	0	0	0	1	0	1	0
Stauroneis smithii var. *sagitta* (Cleve) Hust.	Stsms	1	1	1	1	1	1	1	1
Stauroneisthermicola(J.B.Petersen) J.W.G.Lund.	Sthe	0	1	0	0	0	0	0	0
Staurosira sp.	Stsp	1	0	1	1	0	1	1	1
*Surirellabiseriata*Breb.	Sbis	0	0	0	1	0	1	0	0
Surirellaoliffii Cholnoky	Suol	1	1	0	1	0	0	1	1
*Surirella*sp.	Susp	1	1	1	1	1	1	1	1
Surirellasplendida (Ehrenb.) Kütz.	Sspl	0	0	1	1	0	0	1	0
Surirellatenera Gregory	Sute	0	0	0	1	0	1	0	0
*Tryblionellalevidensis*Wm.Smith	Tlve	1	1	1	1	1	1	1	1
Ulnaria biceps (Kütz.) Lange-Bert.	Ubic	1	1	1	1	1	1	1	1
Ulnaria ulna (Nitz.) Lange-Bert.	Uuln	1	1	1	1	1	1	1	1

Spatial distribution of algal assemblages: The result of the correspondence analysis (CA) based on presence-absence matrix indicates that the first two factorial axes express 40.6% of the total variability (Figure 2). In the upper part of the factorial plan the upstream stations were grouped, while the downstream stations appeared in the lower; except for Noé River (N2). Moreover, the Soumié River samples were on the left part of the factorial plan. S1 was associated with *Navicula angusta* Grunow, *Cymbella* sp. W.Greg, *Navicula heufleriana* (Grunow) Cleve, *Stauroneis legumen* (Ehrenb.) Kütz., *Sellaphora pupula* (Kütz.) Mereschk., while S2 was associated with *Neidium affine* var. *amphirhynchus* (Ehrenb.) Cleve, *Eunotia minor* (Kütz.) Grunow, *Nitzschia subacicularis* Hust., *Luticola cohnii* (Hilse) D.G.Mann, *Pinnularia gibba* var. *sancta* Grunow. Station E1 of Eholié River was associated with *Geissleria* sp., *Cavinula cocconeiformis* (W.Greg. ex Grev.) D.G.Mann & Stickle, *Navicula menisculus* Schum., *Stauroneis smithii* var. *incisa* Pantocsek, *Eolimna minima* (Grunow) Lange-Bert.. Stations N1 (Noé River) and Eh1 (Ehania River) more at the center of the first factorial plan were less significant. Lastly, E2 (Eholié River) and Eh2 (Ehania River) were associated with *Nitzschia terrestris* (J.B.Petersen) Hust., *Luticola* cf. *lagerheimii* (Cleve) D.G.Mann, *Nitzschia recta* Hantzsch. ex Rabenh., *Surirella tenera* W.Greg., *Eunotia praerupta* Ehrenb., *Surirella biseriata* Bréb., *Fallacia monoculata* (Hust.) D.G.Mann, *Eunotia camelus* Ehrenb. and *Gomphonema angustatum* (Kütz.) Rabenh.

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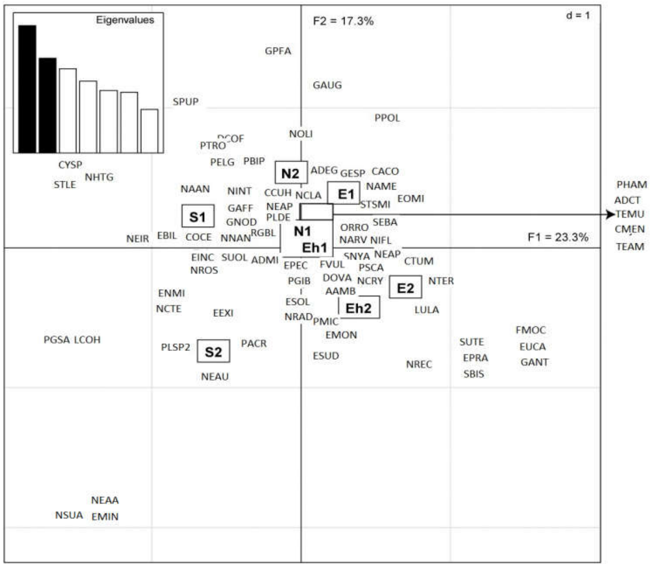

Figure 2: Correspondence Analyse based on presence- absence of taxa in the riversSoumie, Eholie, Ehania and Noe. S = Soumié,E =Eholié, Eh =Ehania, N = Noé, 1 = upstream, 2 = downstream (see table II for code of taxa).

Spatial variation of algal assemblage related to the sampling substrates: The result of the correspondence analysis (CA) indicates that the first two factorial axes express 29.4% of the total variability (Figure 3). These two axes were considered for sample ordination. Along axis 1, the graph shows a clear separation between habitats of open water zone (species in suspension) and river edge (species attached to leaves, wood and stone). Samples of the open water zone are positively correlated to axis 1, while the negative part of this axis includes leaves, wood and stone habitats. Substantial part of taxa is concentrated around the origin of the axes. The samples collected in the open water zone were mainly characterized by the presence of *Craticula cuspidata* (Kütz.) D.G.Mann, *Navicula cryptocephala* Kütz., *Nitzschia terrestris*, *Pinnularia gibba* var. *sancta*, *Pinnularia polyonca* (Bréb.) W.Sm. and *Surirella* sp..

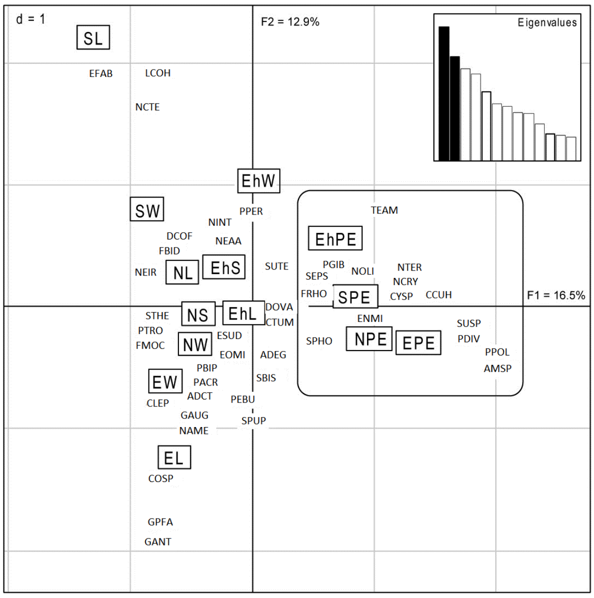

Figure3: Correspondence Analyse based on presence of taxa on different substrates in the rivers Soumie, Eholie, Ehania and Noe. S = Soumié,E =Eholié, Eh =Ehania, N = Noé,PE=pelagic zone,F =leaf,W =wood,P =stone (See table II for code).

A second CA was performed on the periphytic samples to investigate the difference in distribution. The first two factorial axes express 37.8% of the total variability (Figure 4). In the left lower quadrant, the samples taken in Ehania River were grouped associated mainly with *Encyonema minutum* (Hilse) D.G.Mann, *Neidium affine* var. *amphirhynchus* (Ehrenb.) Cleve, *Pinnularia gibba* var. *gibba* (Ehrenb.) Ehrenb., *Sellaphora pseudopupula* (Krasske) Lange-Bert.. In the left upper quadrant, *Eunotia faba* (Ehrenb.) Kütz. and *Luticola cohnii* were mainly associated with the leaves collected in Soumié River while *Fragilaria bidens* Heib., *Navicula cryptotenella* Lange-Bert., and *Neidium iridis* (Ehrenb.) Cleve were associated more with the wood samples from Soumié River. The centre and right part of the factorial plan were grouped the samples taken from the Noé and Eholié Rivers and were linked with *Achnanthidium catenatum* (J.Bílý & Marvan) Lange-Bert., *Achnanthidium exiguum* (Grunow) Czarn., *Diploneis ovalis* (Hilse) A.Cleve, *Eolimna minima* and *Pinnularia biceps* fo. *petersenii* R.Ross. Several leaves collected in the Eholié River were related to *Gomphonema angustatum* (Kütz.) Raben., *Gomphosphenia pfannkucheae* (Cholnoky) Lange-Bert. and *Surirella biseriata*.

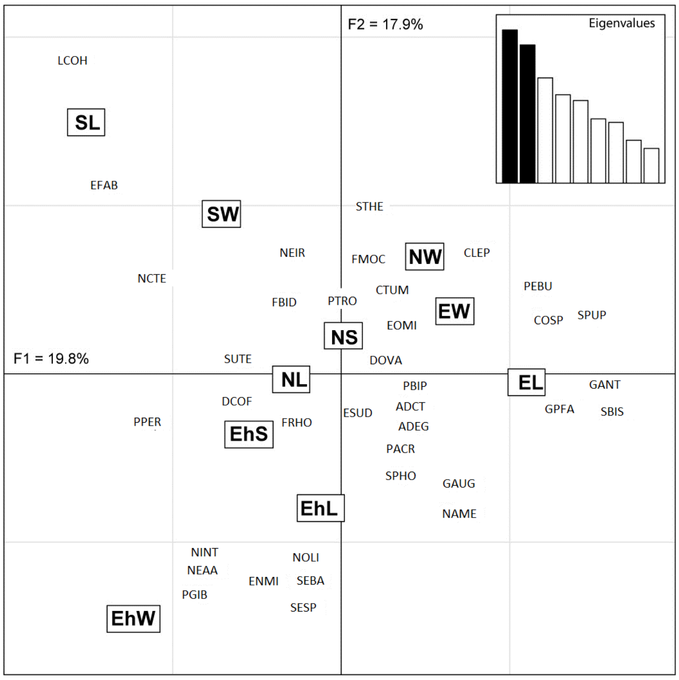

Figure4: Correspondence Analyse base on presence of taxa on the different benthic substrates in the rivers; Soumie, Eholie, Ehania and Noe. S = Soumié,E =Eholié, Eh =Ehania, N = Noé,PE=pelagic zone,F =leaf,W =wood,P =stone (See table II for code).

DISCUSSION

Distribution of the diatoms and substrate choice for the future biomonitoning survey: The diatom flora from the four rivers was rich in taxa (145) in comparison with [15] which recorded 51 diatoms in Agnéby River and 64 diatoms in Bia River. Eighty-one taxa were identified for the first time in Côte d'Ivoire. This study is the first inventory for Côte d'Ivoire and this is the first step in establishing a biomonitoring protocol and program.

Noé River (N1 and N2), that was more at the centre of the first factorial plan in the CA and station Eh1 of the Ehania River, sheltered common taxa as *Nitzschia intermedia* Hantzsch ex Cleve & Grunow known to live in littoral zone of eutrophic river [36]. Station E1 of Eholié River, with nitrate concentrations between 1.57 and 1.91 $mg.l^{-1}$, was characterized by a different set of eutrophic taxa, *Achnanthidium exiguum* (Grunow) Czarn., *Eolimna minima* (Grunow) Lange-Bert.. Stations E2 and Eh2, characterized by higher nitrate concentrations ranging between 2.61 and 2.97 $mg.l^{-1}$ and 1.46 and 2.16 $mg.l^{-1}$ respectively, contained also eutrophic taxa, *Gomphonema angustatum* (Kütz.) Raben. and *Surirella biseriata* Breb. [37] and *Navicula cryptocephala* Kütz. which is tolerant to nitrates [38]. The Soumié River had taxa sensitive to pollution, such as *Navicula angusta* Grunow [37] that were present at S1, while S2, had the cospomolitan taxa *Navicula cryptotenella* Lange-Bert., *Navicula rostellata* Kütz. and *Eunotia minor* (Kütz.) Grunow indicating β-α-mesosaprobic conditions ([18], [36], [38]).

Considering that samples were taken from plankton nets and several different substrates, it could be considered that the inventory is complete. Moreover, the choice of the sampling susbtrates is an important step in establishing a biomonitoring procedure. There was a high statistical similarity within the benthic communities attached to leaves and wood [39]. However, depending on the river, some taxa seemed to have substrate specific preferences such as *Gomphonema angustatum* (Kütz.) Raben., *Gomphosphenia pfannkucheae* (Cholnoky) Lange-Bert., *Luticola cohnii* (Hilse) D.G.Mann and *Surirella biseriata* Kutz. that were associated more closely to leaves. Moreover, the periphyton population from the studied rivers is generally more diverse than those from the open areas of the river. Resuspension of periphyton algae by currents could cause the open waters to have more diversity. This phenomenon is very common in running waters ([40], [41], [42]). According to these authors, the greater the current, the larger amount of algae detached from the substrate, and therefore reduces the diversity of attached algae. In the studied rivers, flow (0.1 to 0.8 m3 / s) is relatively low, therefore the resuspension phenomenon was less important, which would explain the higher species richness of the attached periphyton at different stations. [41] also reported that periphytic microalgae are more diversified than in the open waters in the European rivers. Four species are common to all explored habitats and all were pinnate diatoms. These are *Ulnaria biceps* (Kütz.) Lange-Bert., *Gomphonema parvulum* Kütz., *Nitzschia palea* (Kütz.) W.Sm. and *Gyrosigma acuminatum* (Kütz.) Rabenh.. The pinnate diatoms are exclusively adherent and / or attached algae [43]. The large size of these four diatoms and their habit of forming ribbon-like (*Ulnaria*) or star-shaped colonies (*Nitzschia*) predispose resuspension, which would explain their presence in the open water zone. According to [44], the ability of the algae to stay attached to the substrate during a flow increase varies according to their size, morphology and attachment mode and strength. Small diatoms resist increased flow and are therefore unlikely to be uprooted by the current [42], unlike those of large size. [45] and [29] suggest that these four algae are encountered both in plankton and periphyton. Our findings corroborate their results.

For [36], stones are the preferred substratum for monitoring diatoms in the riverine environment, and almost all diatom indices throughout the world can be applied to the community (i.e. the epilithon) that is found on this substratum. The reason is that they remain in their location unless disturbed by some catastrophic event, like a big flood. This means that they reflect the characteristics of the water from the area in which they live [46].

This work develops a database about diatom flora in the running waters of Ivory Coast. The result indicate that the pinnate diatoms *Ulnaria biceps* (Kütz.) Lange-Bert., *Gomphonema parvulum* Kütz., *Nitzschia palea* (Kütz.) W.Sm. and *Gyrosigma acuminatum* (Kütz.) Rabenh. are common to all explored habitats. Eigthy-one taxa of 145 encountered in those rivers were registered for the first time in Ivory Coast. There is a clear statistical separation between species in suspension and species attached to substrats. This study is the first step in establishing a biomonitoring protocol and program.

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