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## RESEARCH ARTICLE

# AQUATIC ENTOMOFAUNASTRUCTURE INBANCO STREAM (BANCO NATIONAL PARK, COTE D'IVOIRE)

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## Abstract

In this study, a first inventory of aquatic insect in Banco Stream, (Côte d'Ivoire) and the correlations between environmental variables and the abundance of the main taxa were analysed. Seven stations were sampled monthly, over a 1-year period, using a hand net (10 ×10 cm, 250 µm mesh, 50 cm length). 118 insects were recorded. They were distributed among 61 families and eight orders. Aquatic insects richness is clearly dominated by Coleoptera (27 taxa). Chironomidae was the dominant family (76%). The highest values of Shannon-Weaver diversity and Pielou's Evenness index were recorded at upstream station areas (S1 and S2).The Sorensen Similarity among stations varied from 23.53 % (S6 – S7) to 66.67 % (S1 – S2). Rare taxa (FO < 25%) were the most numerous (> 62%) at the different stations. Correlations between the most abundant taxa and environmental parameters using the Focused Principal Component Analysis showed a strong positive correlation between dissolved oxygen and Gomphidae and Libellulidae (Odonata). Chironomidae and Tipulidae (Diptera) abundance were positively correlated with sand.The effects of the civilian prison and other domestic wastes on aquatic insect structure can be mitigated, if this waste is properly channelled and treated before discharge into the Banco Stream.



## Introduction:-

Aquatic macroinvertebrates are an important link in the aquatic food chain (Clarke et al., 2008 ; Vaughan et al., 2012). They are the most important source of food for several species of amphibians, birds and fishs (Xu et al., 2012 ; Camara et al., 2012). Therefore, they play a key role in aquatic ecosystems. Within the aquatic macroinvertebrates, the aquatic insects constitute the most diverse taxonomic group and the most abundant in freshwater environments (Gagnon and Pedneau 2006).

According to Mohd Rasdi (2012), the aquatic insects are an important invertebrate arganism both economically and ecologically. Aquatic insects have frequently been used to indicate changes in the composition responding to indicators of long-term environmental changes in water and habitat quality ( Song et al., 2009 ; Zang et al., 2013 ; Tchakonté et al., 2015). They are good candidates for investigating how changes in communities structure in stream ecosystems might alter ecosystem functionnig, because they occur at various levels of food chain (Rosenberg and

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Resh, 1993).In aquatic environments, they are important elements in the ecological dynamics, playing an important role in the material cycle and in trophic transfers (Hynes, 1970 ; Dunbar et al., 2010). Of the biological quality elements that have been used for water quality assessment, aquatic insects are most often recommended (Santhosh and Ashadevi 2017) due to their varying sensitivity to several abiotic and biotic factors in the environment (El Husseiny et al., 2015).

Streams and rivers are among the most threatened ecosystems of the world (Dudgeon et al., 2006; Hering et al., 2006), particularly those in tropical regions (Boyero and Bailey, 2001).

In Côte d'Ivoire, many studies have dealed about the composition and structure of aquatic insects in some streams (Edia et al., 2007 ; Edia et al., 2010), and fish ponds (Edia, 2013 ;Yapo et al., 2017, Camara et al., 2019).

The Banco Stream (situated in the Banco National Park (BNP)) is subjected to anthropogenic disturbance due to sewage draining by canal coming from the neighbouring cities of BNP (Camara et al., 2009). This disturbance represents a threat for the stream integrity and the aquatic communities, particularly aquatic entomofauna.Several studies (Daget and Iltis, 1965 ; Powell, 1980 ; Camara et al., 2009 ; Camara et al., 2011 ; Camara et al., 2012 ; Camara et al., 2014) have been devoted to aquatic fauna in Banco Stream. But to our knowledge, no study has dealed about the diversity and structure of aquatic insect community in the Banco Stream.

The aims of this study were (i) to determine the composition and structure of aquatic insects along Banco Stream ; and (ii) assess the relationships between the environmental variable and the main insect taxa in Banco Stream.

## Material and Methods:-

### Study area and sampling stations:

The Banco Stream is a short stream (about 9 km long) located in the BNP. This park, whith an area of 3000 ha, is situated in the centre of Abidjan (economic capital) between 5°21' – 5°25'N and 4°01' – 4°05'W (Fig1).

The climate in this park is typical of the equatorial rain forest, comprising four seasons (Girard, Sircoulon and Touchebeuf, 1971) : a great dry season (December – March), a great rainy season (April – July), a small dry season (August – September) and a small rainy season (October – November). Air temperatures in the BNP average 27°C, with an annual precipitation of approximately 1600 – 2500 mm (Kouamé et al., 2008).

Insecta were sampled monthly from October 2006 to November 2007 at seven sampling stations : two stations (S1 and S2) in upstream areas, three (S3, S4 and S5) in midstream areas and the last two (S6 and S7) in downstream areas (Fig. 1). At each station, the length of sampled area covered ten times the channel width (AFNOR, 1992 ; Lazorchak, Klemm and Peck, 1998).

Upstream stations S1 and S2 are characterized by substratum heterogeneity (mud, sand and woody debris), with fragmented leaves. Here, the dominant macrophyte is Thaumatococcusdaniellii and riparian vegetation consists of trees, mainly Turraenthus africanus, Petersianthus macrocarpus andDacryodes klaineana. These upstream stations are not affected by human disturbances.

Midstream stations S3 receives municipal untreated waste waters and surface run-off from Abobo city. The substratum at S3 is mainly sandy, with a lack of aquatic vegetation. Musanga cecropioides and Xanthosoma sp. are the riparian vegetations at this stations. Banco Stream is subject to organic pollution arising from effluents from a civilian prison in the midstream areas. The effluents from this prison are regularly discharged into the river without treatment through a tributary. Station S4 is located on this tributary. Water is eutrophic at this station, with substantial algal growth. Station S5 is situated adjacent to stations S3 and S4 and is lined by Indian bambou trees (90%). Predominant substratum is clay and silt with macrophytes being absent.

At downstream station S6, the banks are characterized by marginal grassy vegetation [Nephrolepis biserrata(Schott, 1834)] and a predominance of trees such as Hallea ledermannii (Krause, 1985)andAlstonia boonei (De Wild, 1914). Predominant substrates at this station are sand and gravel. Station S7 is the last station in the main channel at the downstream areas. At this station, the substratum is sandy to silty, with decaying plant matter. Riparian vegetation consists of trees, mainly Raphia hookeri(Mann and Wendl, 1864) and Parkia bicolor(Chavalier, 1908). There is high vegetation coverage (80%) at this station.

**Data collection:**

Insects were sampled using a triangular hand net (10 x 10 x 10 cm, 250 µm mesh, 50 cm length). For each sample, the net was dragged over the Stream bed for distance of 10 m, maintaining contact with the substrate. In each month of the sampling period, two replicate samples were collected at each station, considering all possible microhabitats over representative sections of the stream. The samples were sieved in the field through a 1mm mesh, and the material retained on the mesh was immediately fixed in 5 % formaldehyde. In the laboratory, the samples were washed unsing 1 mm sieves, then sorted and identified using stereomicroscope (Olympus SZ 30). Insects were determined to the lowest taxonomic level possible (usually genus) using appropriate literature. The keys used in this study are Dejoux et al. (1981) and Tachet et al. (2003). After the identification, the organisms were preserved in 70 % ethanol.

Four environmental variables were used to describe physico-chemical water condition at each sampling station : conductivity (measured in $\mu S.cm^{-1}$ with WTW-LF 340), pH (measured with a ph meter WTW-Ph 330), water temperature (measured in °C using a thermometer built into the pH-meter) and dissolved oxygen (measured in $mg.l^{-1}$ with an oxymeter WTW DIGI 330). All these variables were measured monthly between 7 a.m and 12 a.m in the field before insects sampling. The habitat variables included are current velocity, water depth and wetted channel width, canopy cover and substrate type. Current velocity ($m.S^{-1}$) was measured in mid-channel on five occasions by timing a floating object (polystyrene cube) over five meters stretch of the Stream. It was determined as the average of the five trials. Water depth (m) and wetted channel width (m) were measured (five transects) to the nearest centimetre inside each station, using a decametre. Canopy cover (%) and substrate type (mud, sand, gravel and woody debris as percentage of station bottom area covered by each substrate type) were estimated visually at each sampling station (Arab et al., 2004).

**Data analysis:**

Insects structure was described through taxonomic richness, frequency of occurrence, relative abundance, Sorensen similarity index and diversity index (Shannon-Weaver diversity index and Pielou evenness). The Sorensen similary index was used to eveluate similarity of aquatic insects between stations. The frequency of occurrence(FO) was calculated using the following formula: $FO = (Ni/Nts)\times100$; with Ni = number of samples containing a given species i, and Nts = total number of samples collected. The FO was used to classify taxa following Dajoz (2000): $FO>50$: very frequent species; $25<FO \leq 50$: frequent species; $FO\leq 25$: rare species.Relative abundance is the percentage ratio of the number of individuals in a taxon, from one station to the total number of individuals of all taxa in this station.

Before performing comparison analyses, data normality was checked using Shapiro test. As the biotic and environment data distribution follow non-normal distribution ($P<0.05$), the non- parametric test of Kruskal-Wallis was performed to compare data variability between sampling stations. The Kruskal-Wallis test followed by the multiple comparaison rank test of Tukey were performed to verify significant differences in environmental variables and entomofauna metrics among sampling stations. Analyses were conducted using STATISTICA 7.1 computer package. A level of $p<0.05$ was considered significant.

Focused Principal Component Analysis (FPCA)(Falissard, 1999) was used to assess relationships between the abundance of the main taxa and environmentale variables. FPCA is a variation of the traditional principal component analysis. It uses the same types of matrix as the PCA but differs from it in that it is centred or focused on a variable xi. Indeed, it allows a graphical representation of the correlations that exist between this variable xi and the other variables. The graph provides access not only to the nature (positive or negative) but also to the significance ($p < 0.05$) of the correlations between variable xi and the other variables. It is also possible to observe on the graph the correlations between the other variables. In this study, the FPCA was used to determine the variables that influence the abundance of the main insect taxa that contribute at least 5% of the total abundance. This analysis was performed using the psy package on the R software.

## Results:-

**Environmental variables:**

The water of Banco stream was acid with low variation in pH (3.92 (S4) - 6.99 (S3)) between sampling stations. A low variation was also recorded for water temperature between stations. It varied from 24.7 °C (S1) to 28.4 °C (S4). Water temperature and pH were not significantly different (Kruskal-Wallis, $p< 0,05$) between the sampling stations (Table 1).

The lowest dissolved oxygen (0.3 mg.l$^{-1}$) was observed at station S4 (on tributary) and the highest values (11.94 mg.l$^{-1}$) was recorded at station S2. Dissolved oxygen values were significantly higher in the stream channel stations than that on tributary (station S4). The highest value of conductivity (200 µS.cm-1) was observed at S4. Conductivity was low in the stream channel stations and varied from 17µS.cm$^{-1}$ (S6) to 64µS.cm$^{-1}$ (S3). Unlike to dissolved oxygen, conductivity values were significantly higher at station S4 on tributary. Concerning the current velocity, the lower values (0.01 – 0.04 m.S$^{-1}$) was observed at S4. On the stream channel, current velocity varied from 0.15 m.S$^{-1}$ (S2) to 0.72 m.s-1 (S6). Generally, water depth and wetted channel width increased from upstream to downstream stations. Depth varied from 0.13 m (S1) to 1.2 m (S7) and the width varied from 2.23 m (S2) to 10 m (S7). At station S4, depth ranged between 0.01 to 1.3 m. Kruskal-Wallis test revealed significant difference in water depth and wetted channel width values between the sampling stations S5, S6,S7 and stations S1 and S2.

**Taxonomic richness, composition and frequency of occurrence:**

A total of 118 aquatic insect taxa belonging to 61 families and eight order were recorded (Table 2). The eight orders consisted of Coleoptera, Odonata, Diptera, Trichoptera, Heteroptera, Ephemeroptera, Plecoptera and Lepidoptera. The richnest orders of insects were Coleoptera (27 taxa), Odonata (24 taxa) and Diptera (20 taxa) followed by Trichoptera (17 taxa) and Heteroptera (15 taxa).Ephemeroptera (11 taxa) were collected in both upstream (S1 ; S2) and downstream (S6 ; S7)areas, while Plecoptera (3 taxa) were only found at the upstream stations. Eristalis sp. (Diptera) was recorded only at midstream stations S3 and S4.The number of taxa identified at each station ranged from 21 (S6) to 78 (S2). The analysis of the taxonomic richness showed that station S2 is the most diversified with (78 taxa), followed by stations S3, S7 and S1, with respectively 41, 30 and 29 taxa. The stations S4 and S5 have each one 27 taxa. Station S6 (21 taxa) had the lowest taxonomic richness (Table 2).

Three taxa were common to the seven stations (Eurymetra sp., Chironominae, Tanypodiinae). These taxa had a high occurrence (FO≥50).The table 3 shows the percentage of the very frequent, frequent and rare taxa at the seven stations. The analyse of frequency of occurrence revealed that rare taxa (FO<25%) are the most numerous at all the studied stations with more than 60 % of the taxa identified. The hight values of very frequent (F≥ 50 %) taxa were recorded in upstream stations S1 (5) and S2 (6). Midstream stations S3 registered 3 very frequent taxa. Downstream stations S6 and S7 registered 4 and 3 very frequent taxa respectively. At the tributary station S4, they was any very frequent taxa. Concerning the frequent taxa (25≤ FO <50), the upstream station S2 (13) and the midstream station S3 (11) registered the hight number, while the lowest number were found in the dowstream stations S6 (3) and S7(4). Station S4 (on the tributary) recorded 8 frequent taxa.

**Relative abundance and diversity indices:**

The global abundance of the aquatic insect collected from each sampling stations are shown in figue 2.In terms of total abondance at Banco stream, Diptera (89.28 %) are the most recorded followed by Coleoptera (3.78 %), Odonata (2.89 %), Heteroptera (1.53 %) and Trichoptera (1.19 %) (Fig 2). Ephemeroptera, Plecoptera and Lepidoptera were the least represented groups with least than 1 % each other.At the spatial scale, Diptera were the main component of Insects at all sampling stations. The relative abundance of Diptera ranged from (40.15 %) (S4) to (98.48%) (S3). After Diptera, the Odonata are the second component at the stations S6, with 34.78 % of relative abundance, followed by Coleoptera (28.53 %) at the station S2 (Fig.3).

The relative abundance of the main families of aquatic insect collected at each sampling stations are shown in figure 4.This distribution by station indicate that Chironomidae families were the main component of Insects at all stations. Its relative abundance varies from 42.05 % (S4) to 99.45 % (S3).At the station S4, this familie was followed by Hydrophilidae and Belostomatidae with respectively 26.15 % and 21.53 %. Elmidae (24.36 %) is the second group after the Chironomidae at the station S2.

Shannon-Weaver index is significantly higher in upstream and downstream areas (median > 1.05) (Kruskal-Wallis, p< 0,05). Us the Shannon-Weaver index, the Pielou's Evenness index values are higher in upstream stations S1 and S2 (median > 0.7). This index decreases in midstream area stattions S3 and S4 (median < 0.4), then riser again in the downstream stations S6 and S7 (median > 0.7). Pielou's Evenness index values are significantly lower in midstream stations S3 and S4 than that recorded in upstream and downstream stations (Kruskal-Wallis, p<0,05). The table 4 shown the values of the Sorensen similarity index between the studied stations. The high value of this index were found between the upstream stations S1-S2 (66.67 %), and between the midstream stations S3-S4 (52.05 %) and S3-S5 (50.00 %). The low values were recorded between stations S1-S4 (27.03 %), S1-S7 (26.67 %) and S6-S7 (23.53 %).

**Taxa relationships with environmental variable:**
Focused Principal Component Analysis (FPCA) was performed using environmental variables with a focus on the five most abundance taxa(at least 5 % of total abundance) : Ceratopogonidae (Cera), Chironomidae (Chiro), Tipulidae (Tipu), Gomphidae (Gomph) and Libellulidae (Libe). Thus, the FPCA relating to aquatic insect taxa, revealed that the taxa Ceratopogonodae is significantly and positively correlated with canopy cover (Cano) and current velocity (CurV)($P<0.05$). Chironomidae and Tipulidae were significantly and positivelies correlated with sand (Sand)($P<0.05$).Gomphidae is significantly and positively correlated with canopy cover, current velocity and dissolved oxygen ($P<0.05$). Libellulidae was significantly and positively correlated with sand, dissolved oxygen, canopy cover and current velocity ($P<0.05$)(Fig 6).

## Discussion:-

Among the seven environmental variables mesured in the Banco Stream, water temperature (24.7 - 27.4°C) and pH (3.91 - 7.22) were not significantly different between the sampling stations. Temperature invariability is explained by the fact that this stream is entirely located in a forest. The treetops provide a barrier that reduces the impact of solar radiation on the variation of water temperature along the stream.The range of temperature variation obtained on the Banco Stream is close to those recorded in the forest rivers Soumié (24.4 - 27.4 °C), Eholié (25 - 27.8 °C) and Ehania (24.6 - 27 °C) in Southeast Côte d'Ivoire (Konan, 2008).

The pH observed along the Banco Stream is acidic. This acidity could be attributed to the pH of the substrate.According to Perraud (1971), the soil in the Banco National Park is acidic. The physico-chemical characteristics of a river were closely related to the nature of the soil in its watershed (Arienzo et al., 2001). The pH values measured on the Banco Stream are lower than those obtained in some Ivorian rivers (Diétoa, 2002; Edia, 2008).Dissolved oxygen values were significantly higher (1.8 – 9.6 $mg.l^{-1}$) in the stream channel stations than that registered in the tributary station S4 (0.3 – 3.75 $mg.l^{-1}$). This important decrease of oxygen content at the level of station S4 could be attributed to the activities of microorganismes involved in the mineralization process; knowing that this process consume oxygen. Indeed, this station receives the domestic wastewaters and solid wastes which are the primary pollution sources, rough municipal effluent wastes from Yopougon, particularly from the civilian prison of Abidjan. Unlike to dissolved oxygen, conductivity values were significantly higher (134 – 200 $\mu S.cm^{-1}$) at station S4 (tributary) than those reported in the main channel stations (17 – 64 $\mu S.cm^{-1}$). This low water mineralization in the main channel stations seem to be related to the fact that the stream is located in the forest of Banco National Park. Furthermore, Moss (2007) asserts that the low mineralization of forest stream is due, in part, to the very rapid cycling of biogenic elements in the forest ecosystem.On the other hand, the high conductivity values observed at station S4 are explained by the permanent inflow of wastewater from the municipality of Yopougon, particularly from the civilian prison of Abidjan. However, these conductivity values remain within the same range of variation as those obtained by Edia (2008) on the stream of South-eastern Côte d'Ivoire.

Water depth and wetted channel width increased from upstream to downstream stations. The positivegradient of these parameters from upstream to downstream areas would be related to the morphology of the stream. In fact, from upstream to downstream of the stream, the current velocity decreases while the width of wetted bed increases due to the slope of the terrain, which becomes low in dowstream. Such a gradient has also been noted on someIvorian streams(Niamien-Ebrottié, 2010). Concerning station S4, it is characterized by its low depth and narrow width. This would be explained by the fact that this station is located on the tributary receiving wastewater effluent from the municipality of Yopougon. Indeed, the permanent arrival of wastewater leads to silting of the canal, and decreases of the channel width and depth.

This study represente the first published data on insect community in Banco Stream. A total of 118 taxa belonging to 61 families and eight order were recorded. The taxonomic richness registered in this study is high when compared with studies using the same sampling methods in other Ivoirian streams, such as Soumié (74 taxa), Eholié (69 taxa), Ehania (81 taxa) and Noe (75 taxa) in Southeast Côte d'Ivoire (Ediaet al, 2010).On the other hand, the number of insect taxa found in the Banco Stream is more similar to that reported using the same sampling methods,in suburban forest Stream of Cameroon, whereTchakonté et al. (2015) registered 114 taxa. In Simandou streams (South-eastern Guinea, West-Africa), Edia et al. (2016) registered 129 taxa. In other tropical regions (Vietnam), the aquatic insect richness (268) obtained by Hoang and Bae (2006) using qualitative and quantitative sampling methods was twice as high as that our study.

Among the eight order of aquatic insect identified in this study, Coleoptera are the most diversified with 27 taxa.This high diversity of Coleoptera can be explained by the fact that they appear in both imarginal and larval form in aquatic environments. According to Ben mossa et al. (2014), the Coleoptera colonize various habitats when conditions become hostile to reduced interspecific competition in other species.The taxonomic richness decrease from upstream to downstream areas.Indeed, the upstream stations (S1, S2) regroup 107 taxa, the midstream stations (S3, S5) regroup 61 taxa and the downstream stations (S6, S7) regroup 51 taxa. This decrease in taxa richness could be close by increasing levels of human impact in Banco Stream from upstream to downstream. Stations S3 and S4 were more disturbed by anthropogenic activities (wastewater and domestic wastes from the municipalities of Yopougon and Abobo).High taxonomic richness was registered in the stations with low human impacts (upstream stations S1 and S2). The same pattern was found in temperate (Evans-White et al., 2009), tropical (De Jesus-Crespo and Ramirez, 2011), and moutain stream systems (Miserendino et al., 2008 ; Edia et al., 2016).

The number of taxa very frequent (FO > 50 %) was high at upstream stations S1 and S2. These stations would therefore provide a relatively favourable environment for a large number taxa. In the adverse environmental conditions, four types of reactions are noted, namely the loss of taxa sensitive to slight pollution, a gradual reduction inthe density of some taxa and their disappearance on hyghly polluted stations (Agblonon Houelome et al., 2017), this justifies the high proportion (> 62 %) of rare taxa (FO < 25%) in all the sampling stations of the Banco Stream.

All the Plecoptera and most of the Ephemeroptera and Trichoptera were collected from upstream stations. These taxa required good water quality and their absence in the midstream areas suggest that these organisms cannot tolerate the water in this part of the Banco Stream that also has few suitable habitats. Edia et al. (2007) found a wide distribution of Ephemeroptera and Plecoptera in other Ivoirian localities with high substrate heterogeneity.

Ceratopogon sp. (Ceratopogonidae) was mainly found at upstream station S2 among macrophytes and riparian vegetation, which is similar to the finding of Ogbeibu and Oribhabor (2001) in Ikpoba River in Nigeria. Eristalis sp. (Syrphidae) was recorded in shallow waters in stations S3 and S4 in the Banco Stream, and has also been found in sewage-polluted rivers (Ravera, 2001 ; Rueda et al., 2002). Their ability to survive is the result of using their retractile anak respiratory siphons, and the presence of decaying organic matter, which they feed on (Pennak, 1978 ; Tachet et al., 2010).

In terms of total abondance at Banco Stream, the Diptera order are the most recorded with 89.28 % of relative abundance. Diptera is the most widely distritbuted and frequently the most abundant order aquatic insects in freshwater environments (Armitage et al., 1983). This pattern was also evident in this study, with organisms of this order distributed throughout the stream environmental gradient in high abundances. In this study, Chironomidae families were the main component of Insects at all sampling stations. This families of Diptera are opportunists and tolerant of polluted waters (Tachet et al., 2010; Colas et al., 2013) where they may occur in large numbers (Armitage et al., 1995). Indeed, Chironominae are known as 'blood worms' because they are bright red, due to the presence of hemoglobin in their body fluids that enables them to respire at low oxygen concentrations and live in hypoxic or occasional anoxic bottom mud (Day et al., 2002).

The degree of organization of the insect community in Banco Stream was analyzed through Shannon-Weaver and Pielou's equitability (E) index. The values of the diversity index and equitability are higher at stations located in the upstream (S1, S2) and dowstream areas (S6, S7) than those obtained at stations located in the midstreamareas (S3, S4, S5). This suggests that the insect community in the Banco's midstreamarea is not very diverse and poorly organized. The low values of the diversity index and equitability reflect poorly diversified communities with a low degree of organization (Dajoz, 2000; Camaara et al., 2014). Station S2, with its maximum values of diversity index (H: 2.84) and equitability (E: 0.97), appears to be the most diverse, stable and well-organized station. The aquatic insect community at the midstream (S3, S4, S5) appears very unbalanced with the lowest values of the diversity and equitability indices. Disturbance of the bed in the midstream of the stream by sewage and runoff from the municipalities adjacent to the park destabilizes the insect community by favouring the outbreak of Chironominae (Diptera).

Correlations between the most abundance taxa and environmenta parameter using the Focused Principal Component Analysis (FPCA) show a strong significantly and positively correlation between Chironomidae and Tipulidae with sand. This correlation reveals the ability of those Diptera to live in substrate dominated by sand. According Helson et al. (2006) and Vander Vorster (2010), Chironomidae larvae are both taxonomically and functionally diverse in aquatic sysems, represent most feeding and habit guilds, and have a wide range of tolerance values to varying environmental conditions. Ceratopogonodae is significantly and positively correlated with canopy coverand current velocity. This correlation could be explained by the fact that this taxa is known to live in water cover by riparian vegetation (Camara et al., 2012), and current velocity moderate.Libellulidae and Gomphidae were positively correlated with sand, dissolved oxygen, canopy and current velocity. Indeed, those Odonata are known to live in oxygeneted environments, high canopy, current velocity moderately and substrate dominated by sand. According Dickens and Graham (2002), those families are known moderately tolerant to pollution. Moreover, Gomphidae larva is mostly encountered in station where the substrate is dominated by sand (Allan and Castillo, 2007). They are also efficient indicators of water quality (Ferreira-Peruquetti and De Marco Junior, 2002), due to the preference of both larval and adult stages fo certain environmental condition for their establishment (Corbet, 1999 ; Clausnitzer et al., 2009).

## Conclusion:-

This study identifies for the first time a wide range of aquatic insects in the Banco Stream and identifies differences in taxonomic richness between areas affected to some degree by more human activities. Our results point the need to prioritize conservation actions for the middle Banco Stream especially because Banco Stream is localized in the Banco National Park. The effects of the civilian prison and other domestic waste discharges that are revealed can be mitigated, if this waste is properly channelled and treated before discharge into the water surface in the BNP.

## Acknowlegements:-

The authors are grateful to the « Office Ivoirienne des Parcs et Réserves » and the « Direction des Eaux et Forêts de Côte d'Ivoire » for permitting to access to the Banco National Park.

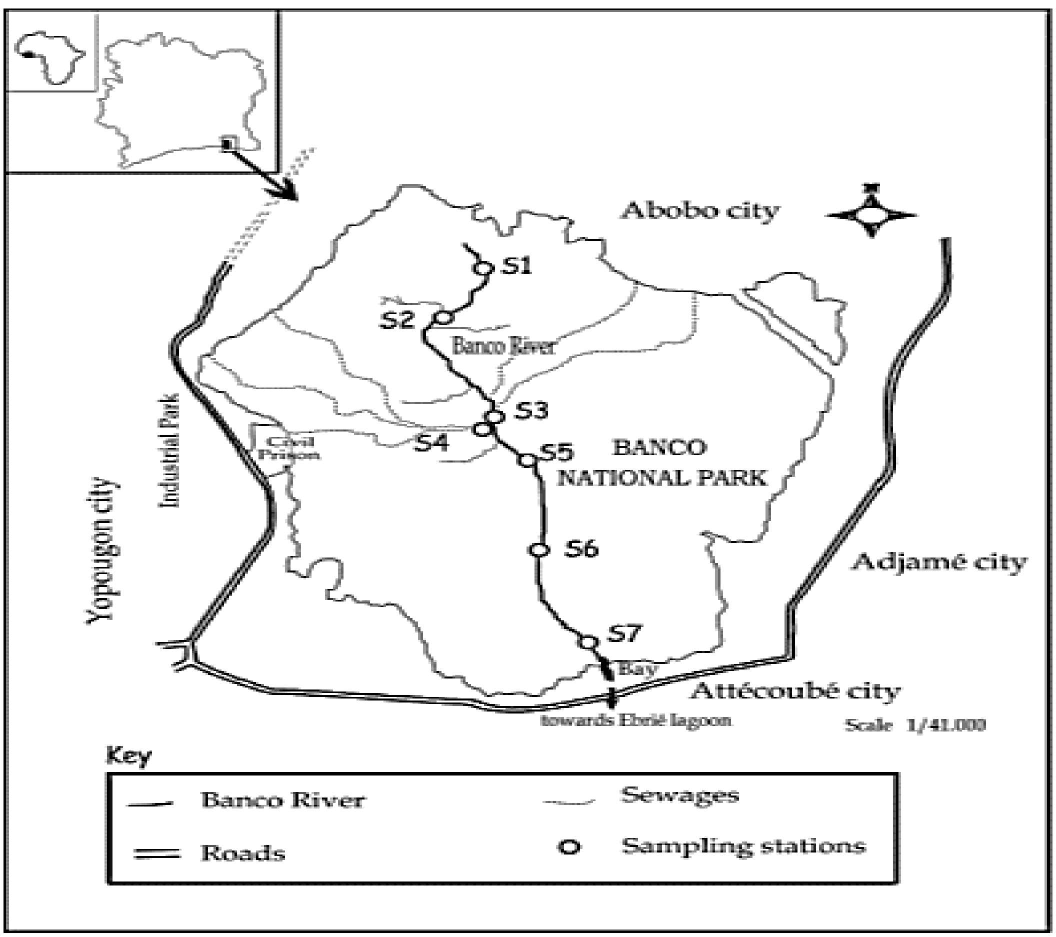


**Figure 1:-** Map of the Banco National Park showing the seven sampling stations. S1-S7 on the Banco stream (Côte d'Ivoire).

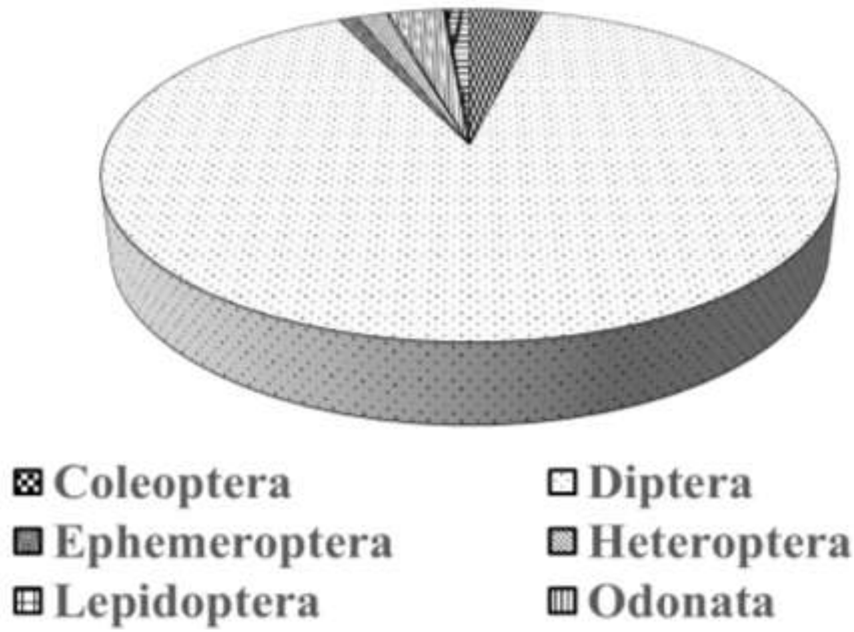


**Figure 2:-** Global abundance of aquatic insect orders collected in the sampling stations of Banco stream (Côte d'Ivoire).

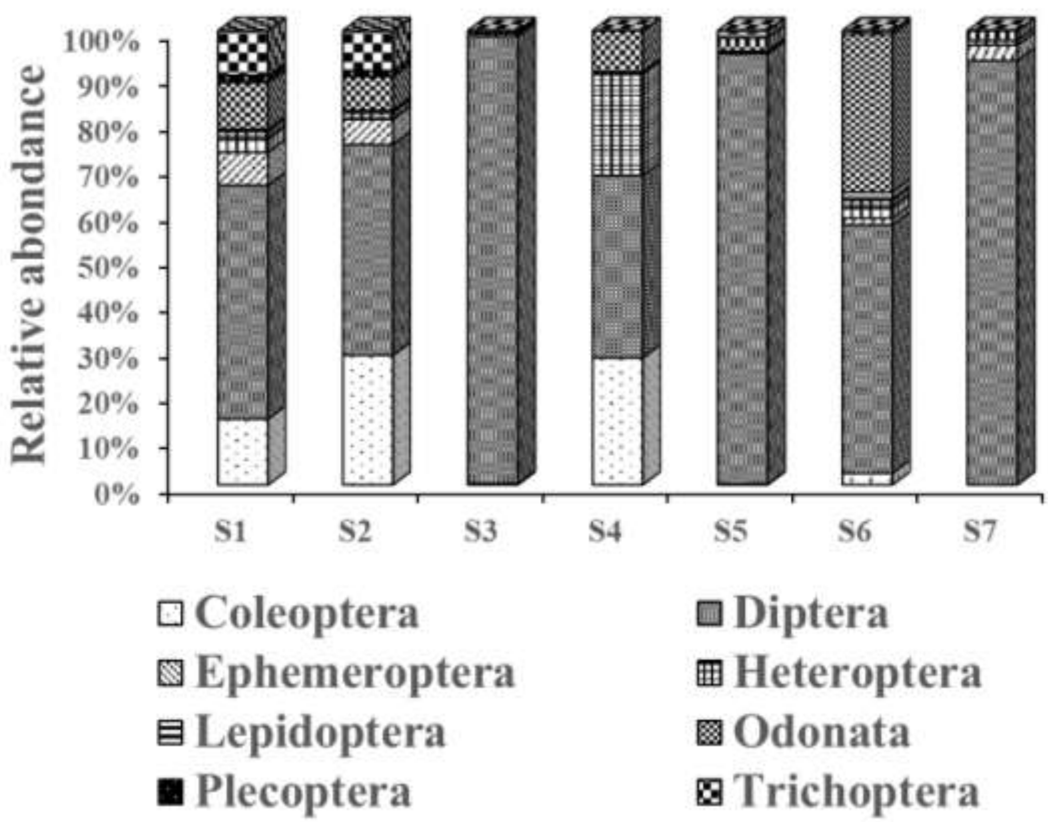


**Figure 3:-** Spatial variations of aquatic insect orders collected in the sampling stations of Banco stream (Côte d'Ivoire).

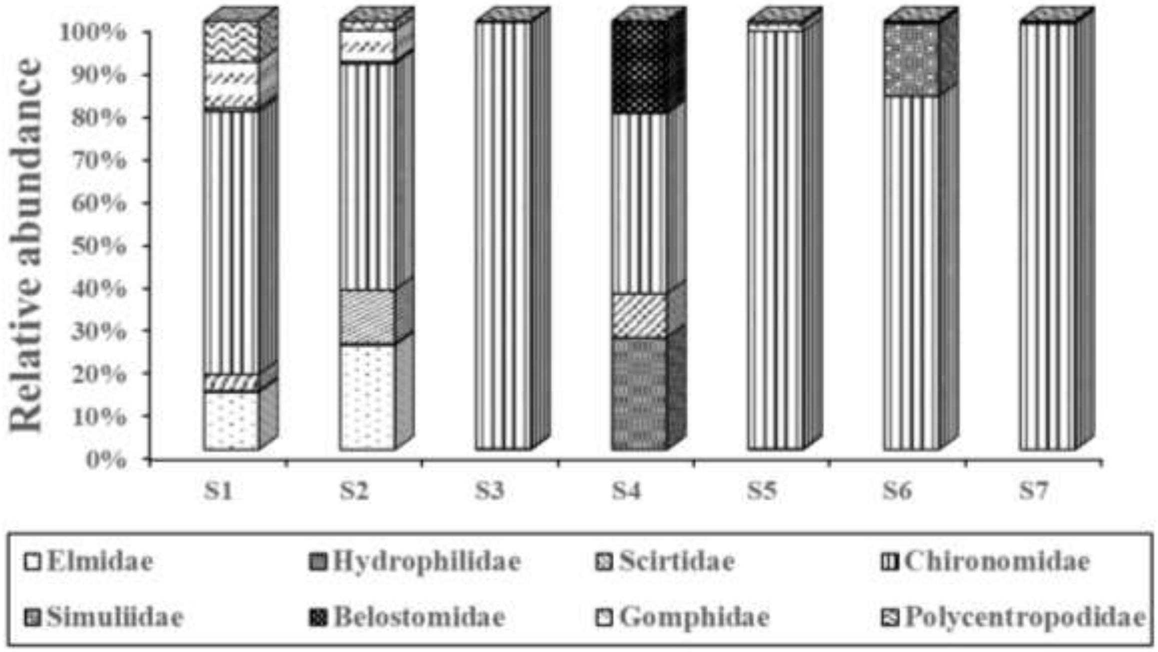


**Figure 4:-** Spatial variations of aquatic insectfamilies collected in the sampling stations of Banco stream (Côte d'Ivoire).

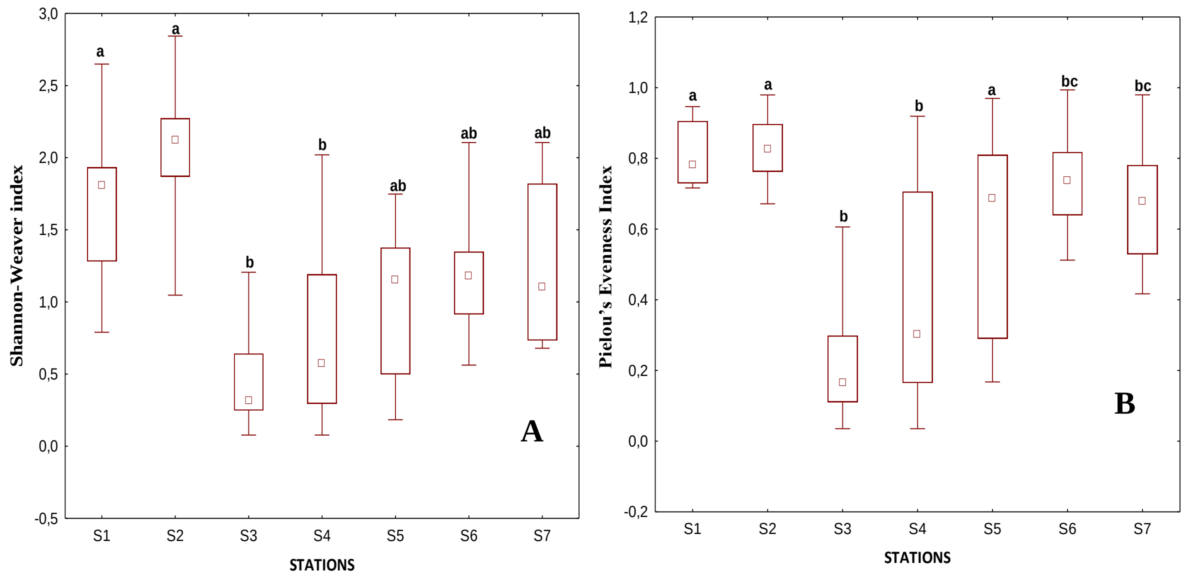


**Figure 5:-** Box –plots showing variation of shannon-Weaver index (A)and Pielou's Evenness index (B) of the insect communities in the sampling stations (S1-S7) of Banco stream. Different letters (a, b and c) on box-plots denote significant differences between them (Kruskal-wallis, $p<0.05$).

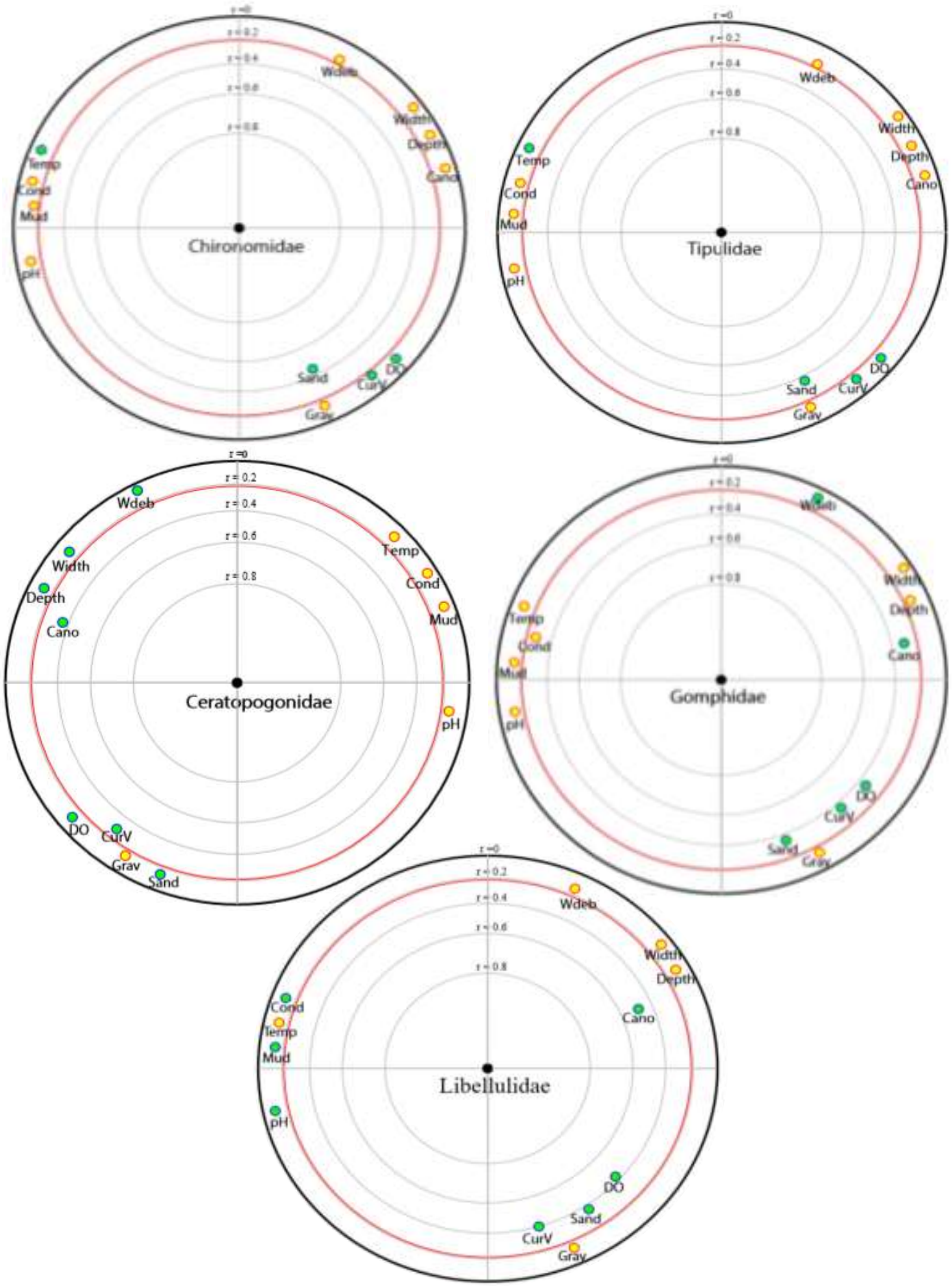


**Figure 6:-** Graphs showing the results of the Focused Principal Component Analysis (FPCA) based on the abundance of taxa with at least 5% of the total abundance as a dependent variable and environmental variables as independent variables. Yellow dots correspond to items negatively correlated to taxa abundance; green dots indicate items positively correlated to taxa abundance. The dots inside the red circle represent items significantly correlated ($p<0.05$) with taxa abundance. The uncorrelated points form right angles to the center of the circle. Temp = temperature; Cond = conductivity; pH = hydrogen potential; Transp = transparency; DO = dissolved oxygen; Grav = gravel; ; Sand = sand; Mud = mud; ; Wdeb = woody debris; ; Width = width ; Depth = depth; CurV = current velocity; Cano = canopy.

**Table 1:-** Environmental variables mesured at the seven sampling stations (S1 – S7) of Banco Stream (Côte d'ivoire).

| | Sampling stations | | | | | | |
|---|---|---|---|---|---|---|---|
| Parameters | S1 | S2 | S3 | S4 | S5 | S6 | S7 |
| pH | 5.21a (4.3-5.69) | 5.21a (3.92-6.53) | 5.5a (3.91-6.99) | 6.20a (5.6-6.87) | 5.3a (4.15 - 7.22) | 4.89a (4.37-6.24) | 4.86a (4.44-5.9) |
| Water temperature (°C) | 25.5a (25.1-26) | 25.6a (24.7-28.8) | 25.9a (25.2-28.2) | 27.4a (25.8-28.6) | 25.65a (24.7-27.9) | 26.55a (25.2-27.8) | 25.85a (24.8-27.9) |
| Dissolved oxygen (mg l-1) | 5.51a (5.1-6.53) | 4.39a (1.92 - 7.04) | 3.94a (1.8-11.94) | 2b (0.3-3.75) | 4.39a (3.3-9.6) | 5.5a (4.98-5.6) | 4.86a (4.44-5.9) |
| Conductivity (µS cm-1) | 21 a (19-22) | 22.4a (20 - 39.2) | 32.2ac (24-64) | 152.2b (134-200) | 35.8c (20-63) | 23.75ac (17-56) | 38.5ac (25.7-54) |
| Water depth (m) | 0.16a (0.13-0.25) | 0.32a (0.21-0.37) | 0.33a (0.24-0.5) | 0.02b (0.01-0.04) | 0.55c (0.25-0.8) | 0.53c (0.31-0.7) | 0.65c (0.6-1.2) |
| Wetted channel width (m) | 3.85a (2.4 - 4.8) | 3.75a (2.23 - 3.9) | 3.7a (3.5 - 5) | 1.20b (1.1-1.3) | 7.45c (6.3 - 7.7) | 4.85ac (4.2 - 5.5) | 8.8d (8-10) |
| Current (m S-1) | 0.35a (0.22-0.53) | 0.28a (0.15-0.64) | 0.33a (0.16-0.67) | 0.02bc (0.01-0.04) | 0.25a (0.19-0.7) | 0.37a (0.3-0.72) | 0.10c (0.05-0.3) |
| N | 12 | 12 | 12 | 12 | 12 | 12 | 12 |

**Note:**
Values are median (minimum and maximum are in parentheses). Different superscript letters (a, b, c, d) in a row show significantdifferences (Kruskal - Wallis, $p<0.05$) between sampling stations.

**Table 2:-** Liste of recorded taxa of aquatic insects at the seven sampling stations (S1 – S7) in Banco Stream (Côte d'Ivoire).

| | | | | **Stations** | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Ordres** | **Familles** | **Taxons** | **Acronymes** | **S1** | **S2** | **S3** | **S4** | **S5** | **S6** | **S7** |
| Ephéméroptères | Ameletidae | ind. | Amel | | * | | | | | |
| | Baetidae | *Labiobaetis* sp. | labio | | * | | | | | * |
| | | *Cloeon* sp. | Cloe | ** | ** | | | | * | ** |
| | | *Pseudocentroptilum* sp. | Psedo | | | | | | | * |
| | Caenidae | *Caenis* sp. | Caeni | | | | | | | * |
| | | *Caenodes* sp. | Caeno | | * | | | | | |
| | | *Caenomedea* sp. | Caen | * | | | | | | |
| | Ephemerellidae | *Ephemerella* sp. | Ephe | | * | | | | | |
| | Leptophlebiidae | *Adenophlebiodes* sp. | Adno | ** | * | | | | | * |
| | Trichorytidae | *Dicercomyxon* sp. | Dice | * | * | | | | | |
| | | *Machadorythus* sp. | Mach | * | | | | | | |
| Plécoptères | Perlidae | *Dinocras* sp. | Dinoc | | * | | | | | |
| | | *Marthamea* sp. | Mart | | * | | | | | |
| | | *Neoperla spio* | Neos | | * | | | | | |
| Odonates | Calopterygididae | *Calopteryx* sp. | Calo | | ** | * | | | | |
| | | *Phaon iridipennis* | Phiri | * | | | | | | |
| | Coenagrionidae | *Enallagma* sp. | Enal | | | | * | | | * |
| | | *Erythromma* sp. | Eryt | | | * | | | *** | ** |
| | | *Pseudagrion* sp. | Pseu | * | * | | * | | | * |
| | Corduliidae | *Cordulia* sp. | Cord | * | * | | | | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | *Oxygastra curtisii* | Oxcu | | | * | | | | |
| | Gomphidae | *Gomphidia* sp. | Gophi | | * | | | * | | |
| | | *Gomphus* sp. | Gophu | | * | | | * | | * |
| | | *Lestinogomphus* sp. | Lest | | * | | | * | | |
| | | *Neurogomphus* sp. | Neuro | *** | *** | | | * | | |
| | | *Ophiogomphus* sp. | Ophi | | * | | | | | |
| | | *Phyllogomphus aethiops* | Phyae | * | *** | * | | * | | ** |
| | Libellulidae | *Brachythemis* sp. | Brach | | * | | | | | * |
| | | *Bradinopyga strachani* | Bradi | | * | * | | * | | |

**Table 2:-** (Continued).

| | | | | Stations | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Ordres** | **Familles** | **Taxons** | **Acronymes** | **S1** | **S2** | **S3** | **S4** | **S5** | **S6** | **S7** |
| Odonates | Libellulidae | *Leucorrhinis* sp. | Leco | | | | | | | * |
| | | *Libellula* sp. | Libe | | * | * | | * | | * |
| | | *Orthetrum* sp. | Orth | | * | *** | * | * | | *** |
| | | *Palpopleura lucia lucia* | Palu | | | * | | | * | |
| | | *Pantala flavescens* | Pafl | | | | | | * | |
| | | *Urothemis* sp. | Urot | | | | * | | | |
| | | Zygonyx sp. | Zygo | * | * | * | * | * | | |
| | Lestidae | ind. | Lesti | | | * | | * | | |
| | Macromiidae | *Phyllomacromia* sp. | Phyl | * | * | | * | | * | |
| Hétéroptères | Belostomidae | *Diplonychus* sp. | Dipl | | | ** | ** | | * | |
| | Corixidae | *Micronecta* sp. | Micr | | | | | * | | |
| | Gerridae | *Eurymetra* sp. | Eury | * | ** | * | ** | * | ** | ** |
| | | *Gerris* sp. | Geri | | * | * | | | | |
| | | *Rhagadotarsus caprivia hutchinsoni* | Rhag | *** | * | | | | | |
| | Hydrometridae | *Hydrometra stagnorum* | Hyst | | | * | | | | |
| | Mesoveliidae | *Mesovelia* sp. | Meso | | | * | | | | |
| | Naucoridae | *Naucoris cimicoides* | Naci | | * | ** | | | | |
| | Nepidae | *Nepa rubra* | Neru | | | * | * | | * | |
| | Notonectidae | *Anisops* sp. | Anis | | | | * | | | |
| | | *Enithares* sp. | Enit | | | | | | * | |
| | | *Notonecta glauca* | Nogl | | | | | | * | |
| | Pleidae | *Plea* sp. | Plea | | | * | * | | | |
| | Ranatridae | *Ranatra linearis* | Rali | * | | | | | ** | |
| | Veliidae | *Microvelia* sp. | Mive | | * | | | | * | |
| Lépidoptères | ind. | ind. | Lepi | | * | * | | * | | * |
| | Pyralidae | ind. | Pyra | | * | | | | ** | * |
| Coléoptères | Dryopidae | *Dryops* sp. | Dryo | | * | | | | | |
| | | *Pomatinus* sp. | Poma | | * | | | | | |
| | Dytiscidae | *Colymbetes* sp. | Coly | | | | * | | | * |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | *Dytiscus marginalis* | Dyma | | * | | | | | |
| | | *Hydaticus flavolineatus* | Hyfl | | | * | | | | |
| | | *Platambus* sp. | Plat | | | * | | | | |
| | Elmidae | *Elmis* sp. | Elmi | | * | | | | | |
| | | *Limnius* sp. | Limn | | *** | | | * | | |
| | | *Oulimnius* sp. | Ouli | | ** | | | | | |
| | | *Potamodytes* sp. | Pota | | ** | | | | | |
| | | *Riolus* sp. | Riol | | ** | | | | | |
| | Eubriidae | *Eubrinax* sp. | Eubr | | * | | | | | |
| | Gyrinidae | *Aulonogyrus* sp. | Aulo | * | | | | | | |
| | | *Gyrinus* sp. | Gyri | | | * | | | * | * |
| | | *Orectochilus* sp. | Orec | ** | * | | | | | |
| | Haliplidae | *Peltodytes* sp. | Pelt | | * | | | | * | * |
| | Hydrophilidae | *Amphiops* sp. | Amph | | | | ** | | | |
| | | *Enochrus* sp. | Enoc | | * | ** | ** | | | * |
| | | *Hydrobius* sp. | Hydr | | * | * | * | | | |

**Table 2:-** (Continued).

| | | | | Stations | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Ordres** | **Familles** | **Taxons** | **Acronymes** | **S1** | **S2** | **S3** | **S4** | **S5** | **S6** | **S7** |
| Coléoptères | Hydrophilidae | *Hydrocara* sp. | Hydra | | | | ** | | | |
| | | *Hydrophilus* sp. | Hydlus | | | * | * | | | |
| | Noteridae | *Noterus* sp. | Note | | | | | | * | |
| | Scirtidae | *Cyphon* sp. | Cyph | * | ** | | * | | | * |
| | | *Hydrocyphon* sp. | Hydcy | | ** | | * | | | |
| | | *Microcara* sp. | Micro | | * | | | | | |
| | | *Scirtes* sp. | Scir | | * | | ** | | | * |
| Trichoptères | Beraeidae | ind. | Bera | * | | | | | | |
| | Ecnomidae | *Ecnomus* sp. | Ecno | | * | | | | | |
| | Hydropsychidae | *Cheumatopsyche* sp. | Cheu | ** | ** | | | * | * | |
| | | *Diplectrona* sp. | Diple | | * | | | | | |
| | | *Hydropsyche* sp. | Hydro | * | * | | | | | |
| | | *Polymorphanisus* sp. | Polym | | * | | | | | * |
| | | *Protomacronema* sp. | Proto | | * | | | | | * |
| | Lepidostomatidae | *Lepidostoma hirtum* | Lehir | | * | | | | | |
| | Leptoceridae | *Oecetis* sp. | Oece | | ** | | | | | |
| | | *Parasetodes* sp. | Pase | | | | | ** | | |
| | Philopotamidae | *Chimarra* sp. | Chima | * | * | | | | | * |
| | | *Philopotamus* sp. | Philo | | * | | | * | | |
| | Polycentropodidae | *Dipseudopsis capensis* | Dicap | *** | ** | | | ** | | |
| | | *Plectrocnemia* sp. | Plec | | ** | | | | | |
| | Rhyacophilidae | *Hyporhyacophila* sp. | Hypor | | * | | | | | |
| | Seriocostomatidae | ind. | Seri | | * | | | | | |
| | Tricorythidae | *Dicercomyxon* sp. | Dicer | | * | | | | | |
| Diptères | Athericidae | *Atheryx* sp. | Athe | | * | | | | | |
| | | *Atrichos crassipes* | Atcra | | * | ** | | | | |
| | Ceratopogonidae | *Ceratopogon* sp. | Cera | ** | ** | * | | * | | * |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | * | | | | | |
| | | Dasyheleinae | Dasy | * | * | * | | ** | | |
| | Chironomidae | Chironominae | Chiro | *** | *** | *** | ** | *** | *** | *** |
| | | Orthocladiinae | Orcla | | * | * | | | | |
| | | Tanypodinae | Tany | *** | *** | ** | ** | *** | *** | *** |
| | Culicidae | *Culex* sp. | Culex | | | * | * | | | |
| | Dixidae | ind. | Dixi | | * | | | | | |
| | Dolichopodidae | ind. | Dolic | | | * | * | | | |
| | Empididae | Clinocerinae | Clino | | * | ** | * | * | | |
| | Limoniidae | *Pilaria* sp. | Pila | | * | ** | | ** | | |
| | Psychodidae | ind. | Psyc | | | ** | | * | | |
| | Ptychopteridae | *Ptychoptera* sp. | Ptyc | | * | | | | | |
| | Scatophagidae | *Acanthocnema* sp. | Acan | | | ** | | * | | |
| | Simuliidae | *Simulium* sp. | Simu | * | * | ** | | | *** | |
| | Stratiomyidae | ind. | Strat | | | * | | | | |
| | Syrphidae | *Eristalis* sp. | Erist | | | ** | * | | | |
| | Tabanidae | *Tabanus* sp. | Taba | | ** | | | | | * |
| | Tipulidae | *Tipula* sp. | Tipu | ** | * | *** | * | ** | * | |
| **8** | **61** | **118** | **118** | **29** | **78** | **41** | **27** | **27** | **21** | **30** |

*** Veryfrequent (FO>50%), **frequent (25% ≤ FO ≥50%), *rareoccurrence (FO<25%)

**Table 3:-** Proportion of aquatic insect very frequent (***), frequent (**) and rare (*) insect taxa at the seven sampling stations in the Banco stream (Côte d'Ivoire).

| | Sampling stations | | | | | | |
|---|---|---|---|---|---|---|---|
| F O | S1 | S2 | S3 | S4 | S5 | S6 | S7 |
| Very frequent (%) | 17.24 | 7.69 | 7.31 | 0 | 7.4 | 19.04 | 10 |
| Frequent (%) | 20.68 | 16.67 | 26.82 | 29.62 | 18.51 | 14.28 | 13.33 |
| Rare (%) | 62.06 | 75.64 | 65.85 | 70.37 | 74.07 | 66.67 | 76.67 |

**Table 4:-** Values of the Sorensen similarity index between the seven sampling stations (S1-S7) of the Banco stream (Côte d'Ivoire).

| | Sampling stations | | | | | | |
|---|---|---|---|---|---|---|---|
| | S1 | S2 | S3 | S4 | S5 | S6 | S7 |
| S1 | | | | | | | |
| S2 | 66.67 | | | | | | |
| S3 | 36.78 | 40.34 | | | | | |
| S4 | 27.03 | 33.96 | 52.05 | | | | |
| S5 | 38.37 | 41.90 | 50.00 | 27.12 | | | |
| S6 | 40.63 | 29.17 | 31.75 | 32.00 | 28.57 | | |
| S7 | 26.67 | 31.78 | 40.54 | 36.07 | 26.67 | 23.53 | |

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