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Aquatic insect community structure in four coastal streams (Cote d'Ivoire, West Africa)

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Abstract: The structure of aquatic insect assemblages in four coastal streams in the southeast Ivory Coast was investigated. The samples were collected between July 2003 and March 2005 at eight sampling sites (2 per stream: 1 upstream and 1 downstream). To analyse patterns of aquatic insect assemblages, the self-organizing map, a non-linear clustering technique, was used. The variables most able to discriminate between the clusters defined by the self-organizing map were identified by a discriminant function analysis. Samples were classified into four clusters, mainly related to the local environmental status of sampling sites. Sites with lower human pressure had higher aquatic insect richness compared to those from the most populated ones. Moreover, conductivity, total dissolved solids and wetted width were the most dominant variables governing aquatic insect richness pattern in the four studied streams. As conductivity and total dissolved solids depend mostly on the use of the surrounding landscape, aquatic insect conservation policy must therefore integrate riparian landscape management.

Key words: Aquatic insects, assemblages, coastal streams, Ivory Coast, self-organizing map, structure

INTRODUCTION

The natural distribution of organisms is determined primarily by their environmental requirements[1]. Thus, understanding community patterns with respect to environmental features is a fundamental basis for ecosystem management[2]. Especially in aquatic ecosystems, macroinvertebrate communities are important for monitoring changes of the target system[3]. Stream macroinvertebrates have a range of environmental preferences and represent a diverse group that integrates ecosystem changes over time[4]. Moreover, according to Minshall[5], bottom-dwelling invertebrates, notably aquatic insects which are the dominant taxon in most freshwater ecosytems[6], are primary food resources for predators such as fishes and represent sensitive indicators of overall aquatic ecosystem health. The value of aquatic macroinvertebrates as indicators of aquatic and terrestrial change has long been recognized with the vast majority of the work on aquatic bioindicators focusing mainly on temperate systems[7]. However, there is growing interest in Africa in the use of aquatic invertebrates as indicators of water quality and ecosystem change[7-12].

Despite their importance in stream ecosystems, aquatic insects are little known in tropical areas[13-14]. In Ivory Coast, among studies devoted to macroinvertebrate fauna[15-21], four were conducted in the southeast Ivory Coast. These studies only described the assemblage pattern of macroinvertebrate fauna of some streams of this area[17-19]. Kouadio *et al.*[20] described the distribution of benthic macroinvertebrate communities in the Ebrié Lagoon.

In this work, we focussed on four small coastal streams in the southeast Ivory Coast. Despite the lack of ecological information on these systems, they play an important role for human populations. These streams are used for domestic activities (drinking, cooking, bathing, fisheries...). It is therefore important to preserve these water resources and maintain the biotic integrity of these ecosystems. Such management requires the knowledge of how the aquatic communities are related to the environment[22].

This approach needs two steps: i) samples are clustered into groups on the basis of biological attributes and ii) the groups are related to environmental data, for example by discriminant analysis[23]. Clustering samples using biotic attributes such as aquatic insects, we deal with ecological data that are bulky, nonlinear and complex, showing noise, redundancy, internal relations and outliers [24]. So, to analyse the pattern of the aquatic insect distribution, we used an unsupervised artificial neural network, the self-organizing map (SOM), which is a clustering technique capable of displaying patterns in complex data sets[25]. This method has proven to be effective in characterizing distribution patterns in community ecology analysis[26] with the advantage of representing non-linear relationships [27].

This study aimed i) to determine the pattern of aquatic insect assemblages in four coastal streams located in the southeast of Ivory Coast and ii) to determine the environmental variables which govern these assemblages.

MATERIALS AND METHODS

Study area: The study was undertaken in four coastal streams located in the southeast of Ivory Coast: Soumié, Eholié, Ehania and Noé streams (**Figure 1**). The basic characteristics of these streams are summarized on the **Table 1**. In each of these coastal streams, two sampling sites were retained: one upstream and the other one downstream (**Figure 1**). **Table 2** summarizes environmental characteristics of these sites.

Table 1: Characteristics of the four study Rivers.

River	Catchment area (km^2)	Length (km)	Slope ($m.km^{-1}$)	Mean annual flow ($m^3.s^{-1}$)
Soumié	395	41	3.31	11.76
Eholié	373	35	2.96	11.4
Ehania	585	70	2.36	15.74
Noé	238	30	1.45	9.56

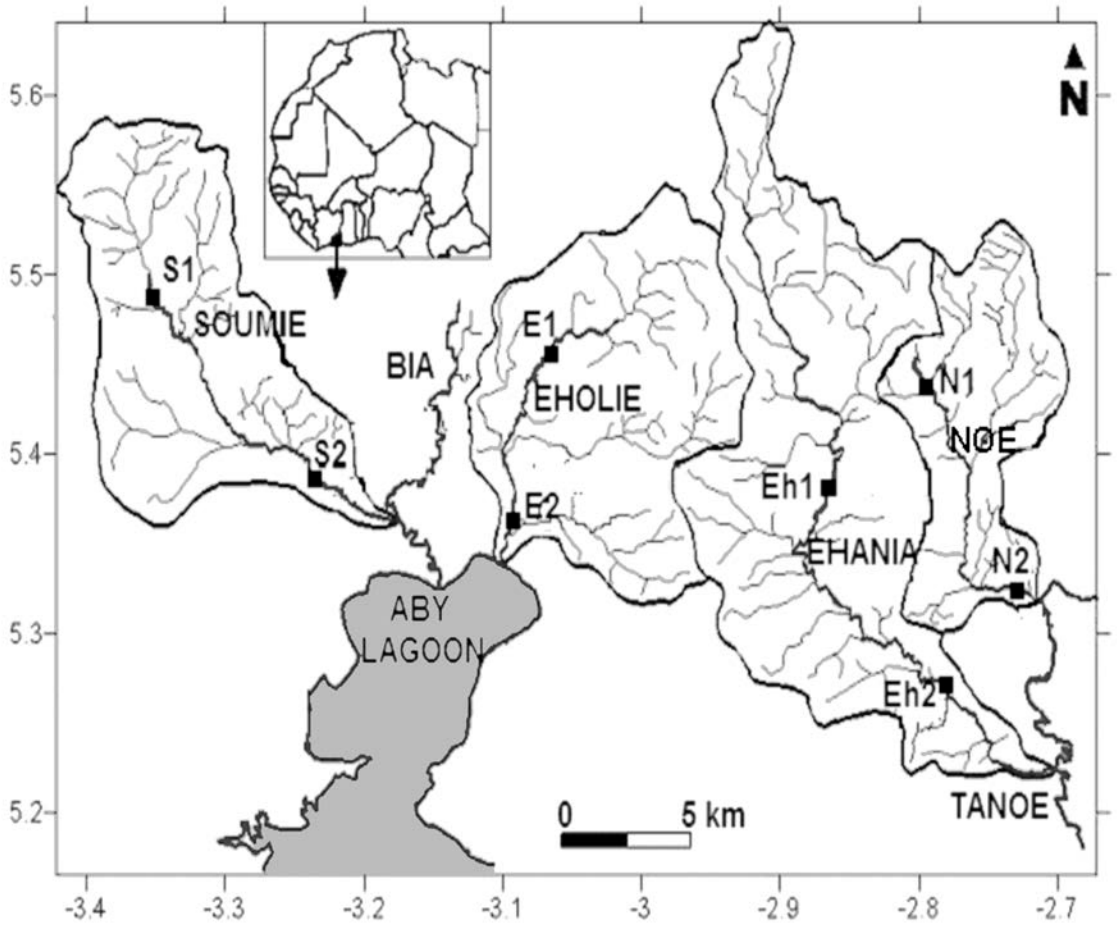


Figure 1: Location of the study area showing the four studied rivers. Dot marks indicate the sampling points on the four rivers. In station names, the letter indicates the river name (S: Soumié; E: Eholié; Eh: Ehania; N: Noé) and the number shows the station position on the river (1 = upstream and 2 = downstream).

Table 2: Characteristics and environmental variables (mean ± SE) of the eight study sites. Very low: a few dispersed houses along the banks, Low: discontinuous habitat building along the banks, High: continuous habitat.

Parameters	Sampling sites							
	Soumié River		Eholié River		Ehania River		Noé River	
	Site S1	Site S2	Site E1	Site E2	Site Eh1	Site Eh2	Site N1	Site N2
Geographical positions	05° 29' N 03° 22' W	05° 24' N 03° 17' W	05° 28' N 03° 08' W	05° 23' N 03° 08' W	05° 24' N 02° 55' W	05° 17' N 02° 50' W	05° 28' N 02° 51' W	05° 18' N 02° 46' W
Water temperature (°C)	25.0 (0.38)	25.3 (0.41)	25.8 (0.52)	25.9 (0.37)	25.4 (0.29)	25.8 (0.38)	25.4 (0.23)	25.9 (0.39)
pH	7.1 (0.12)	6.8 (0.14)	7.0 (0.06)	7.0 (0.06)	7.1 (0.09)	6.9 (0.09)	7.0 (0.09)	6.7 (0.17)
Conductivity ($\mu s.cm^{-1}$)	57.4 (1.90)	42.6 (1.42)	55.2 (1.68)	60 (1.44)	64.1 (1.31)	54.9 (2.39)	64.2 (1.67)	54 (1.34)
Total dissolved solids ($mg.L^{-1}$)	27.3 (0.94)	20 (0.53)	25.8 (0.75)	26.8 (0.70)	29.6 (0.53)	25.8 (1.91)	30.1 (0.85)	25.1 (0.58)
Dissolved oxygen ($mg.L^{-1}$)	4.4 (0.34)	5.3 (0.49)	6 (0.62)	7.1 (0.76)	5.2 (0.54)	7.4 (0.50)	7.2 (0.49)	7.3 (0.56)
Secchi disk transparency (m)	0.61 (0.06)	0.60 (0.07)	0.52 (0.05)	0 .53 (0.04)	0.74 (0.03)	0.50 (0.03)	0.58 (0.05)	0.44 (0.03)
Canopy (%)	35	55	70	85	40	45	5	10
% Rock in substrata	0	25	0	0	0	0	0	20
% Gravel in substrata	35	10	0	10	20	20	10	35
% Sand in substrata	45	40	30	50	20	45	40	25
% Clay/mud in substrata	20	25	70	40	60	35	50	20
Population density	Very low	Very low	Very low	High	Low	Very low	Low	High
Adjacent land use	Cultivated	Cultivated	Riparian forest	Habitations Cultivated	Habitations Cultivated	Riparian forest	Habitations Cultivated	Habitations

Aquatic insect and environmental variable collection: Aquatic insects were collected at each sampling site during eight sampling periods (i.e. four during the rainy season and four during the dry season) between July 2003 and March 2005. These macroinvertebrates were sampled by means of drift net (mesh size: 250µm) and hand net (mesh size: 250µm). Drifting organisms were collected using a drift net suspended from a hand held rope. The openings of the net were orientated against river flow for 15 minutes.

For the hand net, samples were taken by submerging the net and sweeping it through the water column for a distance of ten meters. The net was also bumped and dragged against the bottom substrate to dislodge and collect organisms. All material collected was placed in a sieve bucket. Pieces of vegetation were washed into the net and discarded. Two replicate samples were collected at each site and at each date. The samples were fixed in 10% formaldehyde. The three samples (one collected by drift net and two by hand net) at each site and each sampling period were pooled for analysis. In the laboratory, specimens were sorted and identified to the lowest taxonomic level possible by means of the keys in Déjoux *et al.*[15], Barber-James and Lugo-Ortiz[28], de Moor and Scott[29], and Samways and Wilmot[30], and by consulting specialists.

During each sampling period at each sampling site, water temperature, pH, conductivity, total dissolved solids and dissolved oxygen were measured with portable sensors. Current velocity, depth at the sampling point and wetted width were assessed in order to characterize the study sites. Surface current velocity was obtained by timing a bobber (five time average) [31]. Secchi disk transparency was measured with a standard 20-cm-diameter Secchi disk.

Data analysis: A species occurrence data set was arranged as a matrix of 64 rows (i.e. the eight sampling sites on eight sampling periods) and 65 columns (i.e. taxa). Rare taxa (taxa which appeared in less than 5% of the samples) were removed from the analyses. Species occurrence was used to avoid biases due to both patchiness in aquatic insect spatial distribution and temporal dynamics of abundance[32]. Each of the 64 samples of the data set can be considered as a vector of 65 dimensions. The species occurrence data set was patterned by training the SOM.

The architecture of the SOM consisted of two layers of neurons (or nodes): i) the input layer that was composed of 65 neurons connected to each vector of the data set and ii) the two-dimensional output layer that was composed of 20 neurons (i.e. a rectangular grid with 5 by 4 neurons laid out on a hexagonal lattice). We chose a 20 neuron grid because this configuration presented minimum values of both quantization and topographic errors, which are used to assess classification quality[2]. The SOM algorithm calculates the connection intensities (i.e. vector weights) between input and output layers using an unsupervised competitive learning procedure [25], which iteratively classifies samples in each node according to their similarity in species composition.

The SOM preserves the neighbourhood so samples with close species occurrences are grouped together on the map, whereas samples with very different species occurrences are far from each other. The connection intensity of the SOM corresponds to the probability of occurrence of a species in a group of samples, and can be displayed on the map as shades of grey: the darker the colour, the higher the probability (e.g., black means a species occurred in >90% of the samples)[27]. For more details concerning the SOM algorithm and its applications, we refer the readers to Kohonen[25], Giraudel and Lek[33] and Park *et al.*[2]. The analysis was carried out using the SOM toolbox (version 2) for Matlab® developed by the Laboratory of Information and Computer Science at the Helsinki University of Technology (http://www. cis.hut.fi/ projects/ somtoolbox/).

Taxa closely associated with each cluster defined by the SOM were sought using the Indval method [34]. In this approach, taxa mostly encountered in a given cluster are considered to be characteristic of that cluster. For each taxon, the Indval index value was statistically tested using 999 random permutations [34]. To

determine if a taxon was an indicator, we examined only the significance of this test at statistical level $\alpha = 5\%$.

To evaluate between-cluster differences in species richness, the Kruskal-Wallis test, a non-parametric analysis of variance, was used. This test was followed by Mann-Whitney test to identify specific differences. Moreover, we applied a proportion test based on χ^2 likelihood ratio statistics (i.e. G-test with Yates' correction[35]) in order to assess whether aquatic insect assemblages associated with each cluster were related to seasonal and spatial factors (i.e. rainy and dry seasons; relatively undisturbed and disturbed areas).

We also employed a discriminant function analysis (DFA) to identify the variables most able to discriminate between the clusters defined by the SOM on the basis of biological attributes [36]. To do this, the normalized weighting factor of each environmental variable was calculated to determine their contribution in sample clustering. An environmental descriptor was regarded as most able to discriminate between the clusters when its weighting factor, in absolute value, was at least 0.7. We assessed the accuracy of the DFA by applying a 'leave-one-out' cross-validation test [37]. This test consists of removing one observation from the original matrix followed by DFA on the remaining observations to predict the group membership of the omitted observation. This operation was repeated for all of the observations of the data matrix. These analyses were conducted using the R package [38].

RESULTS

A total of 115 taxa of aquatic insects belonging to 51 families and ten orders were recorded (**Appendix**). The richest orders of insects were Diptera (32 taxa) and Ephemeroptera (24 taxa), followed by Coleoptera (18 taxa). Overall, the macroinvertebrate fauna was predominantly composed of eight taxa (*Labiobaetis gambiae*, *Polypedilum* sp., *Cricotopus* sp., *Caenis* sp., *Tanytarsus* sp., *Simulium damnosum*, *Dicercomyzon* sp. and *Nanocladius* sp.), which were present in more than 50 % of the samples.

Appendix. List of the aquatic insect taxa found at the eight sampling sites. * indicates the presence of taxa

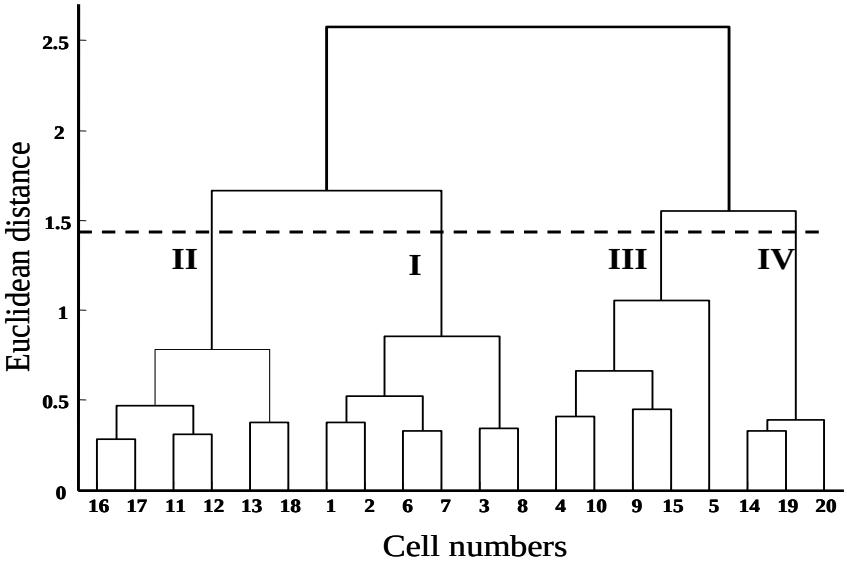
			Soumié		**Eholié**		**Ehania**		**Noé**	
Orders	**Families**	**Taxa**	**S1**	**S2**	**E1**	**E2**	**Eh1**	**Eh2**	**N1**	**N2**
Collembola	Arthropleona			*				*	*	*
Ephemeroptera	Leptophlebiidae	*Adenophlebiodes* sp.	*	*	*	*	*	*		
		Choroterpes sp.	*	*	*	*	*	*		*
		Euthraulus sp.	*	*			*	*		*
		Hyalophlebia sp.				*				
		Thraulus sp.	*	*		*	*	*		*
	Tricorythidae	*Dicercomyzon* sp.	*	*	*	*	*	*	*	*
		Tricorythus sp.	*	*	*	*	*	*		*
	Machadorythidae	*Machadorythus maculatus*			*	*				
	Ephemerythidae	*Ephemerythus* sp.	*	*			*	*		
	Polymitarcyidae	*Ephoron* sp.						*		*
	Caenidae	*Caenis* sp.	*	*	*	*	*	*	*	*
	Baetidae	*Afrobaetodes* sp.			*		*			*
		Bugilliesia sp.		*						
		Cloeodes dentatus				*				
		Cloeon sp.							*	*
		Cheleocloeon yolandae	*		*			*	*	
		Dabulamanzia babaora	*	*						
		Labiobaetis gambiae	*	*	*	*	*	*	*	*
		Procloeon sylvicola	*	*	*	*	*	*	*	*

			Soumié		Eholié		Ehania		Noé	
Orders	**Families**	**Taxa**	**S1**	**S2**	**E1**	**E2**	**Eh1**	**Eh2**	**N1**	**N2**
		Susua sp.	*	*					*	
	Oligoneuriidae	*Elassoneuria* sp.			*			*		
	Heptageniidae	*Afronurus* sp.	*	*	*	*	*	*	*	*
		Compsoneuria njalensis	*	*	*	*	*	*	*	*
		Notonurus sp.	*	*		*	*	*	*	
Plecoptera	Perlidae	*Neoperla* sp.					*			
Odonata	Calopterygidae	*Phaon iridipennis*					*			
	Coenagrionidae	*Coenagrion* sp.	*	*	*		*	*	*	
		Pseudogrion sp.			*					
	Gomphidae	*Lestinogomphus angustus*		*		*		*	*	
		Microgomphus sp.		*	*					
		Paragomphus sp.	*				*	*	*	
		Phyllogomphus aethiops			*	*	*	*	*	
	Cordulegasteridae	*Cordulegaster* sp.	*							
	Libellulidae	*Libellula* sp.			*	*				
		Olpogastra sp.					*	*		
		Zygonyx sp.		*						
		Palpopleura sp.					*			
	Macromiidae	*Macromia* sp.	*	*	*		*	*	*	*
		Phyllomacromia sp.	*	*	*	*	*		*	
	Chlorocyphidae	*Chlorocypha* sp.					*			
Heteroptera	Pleidae	*Plea* sp.		*		*	*		*	
	Notonectidae	*Anisops* sp.		*	*			*	*	
	Corixidae	*Micronecta scutellaris*	*		*					*
	Hydrometridae	*Hydrometra* sp.					*		*	
Heteroptera	Veliidae	*Microvelia* sp.		*			*	*	*	
	Veliidae	*Rhagovelia reitteri*	*	*	*		*	*		
	Gerridae	*Eurymetra* sp.			*	*	*	*	*	
		Gerris sp.	*							
	Belostomatidae	*Diplonychus* sp.			*					
		Limnogeton fieberi					*			
Lepidoptera	Crambidae					*	*	*	*	*
Hymenoptera			*	*			*	*		
Coleoptera	Gyrinidae	*Orectogyrus* sp.	*	*				*		
	Dytiscidae	*Copelatus* sp.							*	
		Dytiscus sp.	*		*		*		*	
		Laccophilus sp.	*	*	*		*	*	*	
	Hydrophilidae	*Enochrus* sp.						*		*
		Hydrobius sp.		*						*
	Elmidae	*Potamophilus* sp.					*			
		Potamodytes sp.		*			*		*	
		Elmis sp.	*	*	*	*	*	*	*	*
		Esolus sp.		*	*	*	*	*	*	*
		Limnius sp.	*	*	*	*	*	*	*	*
		Normandia sp.	*	*	*				*	
		Riolus sp.	*	*	*	*	*	*	*	*
		Dupophilus sp.		*	*	*	*	*	*	
		Oulimnius sp.	*		*	*	*			
		Macronychus sp.	*				*	*		
	Helodidae		*							
	Hydroscaphidae	*Hydroscapha* sp.		*						

			Soumié		Eholié		Ehania		Noé	
Orders	**Families**	**Taxa**	**S1**	**S2**	**E1**	**E2**	**Eh1**	**Eh2**	**N1**	**N2**
Trichoptera	Hydropsychidae	*Cheumatopsyche* sp.	*	*				*	*	
		Polymorphanisus sp.								*
	Polycentropodidae	*Neureclipsis* sp,				*				
	Ecnomidae	*Ecnomus* sp.					*	*		
	Hydroptilidae	*Afritrichia* sp.	*				*	*	*	
		Hydroptila sp.			*		*		*	
		Orthotrichia sp.		*	*	*			*	
	Leptoceridae	*Ceraclea* sp.		*	*	*	*	*		
		Leptocerus sp.	*				*	*		
		Oecetis sp.	*	*	*			*	*	
		Triaenodes sp.		*		*				*
		Parasetodes sp.	*	*	*					
Diptera	Psychodidae									*
	Ptychopteridae	*Ptychopteria* sp.								*
	Chaoboridae	*Chaoborus* sp.								*
	Culicidae	*Aedes* sp.					*			
		Anopheles sp.	*	*	*		*	*	*	
		Culex sp.			*					
		Culicinae	*							
	Simuliidae	*Simulium damnosum*	*	*		*	*	*	*	*
	Ceratopogonidae	*Ceratopogon* sp.	*	*	*	*	*	*	*	
		Dasyheleinae							*	
Diptera		Forcipomyinae						*		
	Chironomidae	*Ablabesmyia* sp.	*	*	*	*	*	*	*	*
		Chironomus sp.	*	*	*	*	*	*	*	*
		Clinotanypus claripennis		*	*	*	*	*	*	*
	Chironomidae	*Cricotopus* sp.	*	*	*	*	*	*	*	*
		Cryptochironomus sp.	*	*	*	*	*	*	*	*
		Lauterborniella sp.						*		
		Nanocladius sp.	*	*	*	*	*	*	*	*
		Nilodorum sp.			*	*	*	*	*	*
		Orthocladiinae	*		*				*	
		Polypedilum sp.	*	*	*	*	*	*	*	*
		Procladius sp.			*					
		Stenochironomus sp.	*		*	*	*			
		Stictochironomus sp.	*	*	*	*	*	*	*	*
		Tanypus sp.			*		*		*	*
		Tanytarsus sp.	*	*	*	*	*	*	*	*
	Stratiomyidae								*	
	Empididae	Hemerodromiinae							*	*
	Athericidae	*Atherix* sp.	*			*	*	*		*
	Anthomyidae			*						
	Tabanidae	*Tabanus* sp.			*		*	*		*
	Tipulidae							*	*	

The samples were classified by the SOM according to their species composition in the 20 output nodes, so that each node included samples with similar species (**Figure 2a, b**). The units of the SOM map were classified into two main groups based on the cluster analysis with Ward algorithm. Each main group can be subdivided into two subgroups giving rise to four clusters (I, II, III and IV) (**Figure 2b**). Different shaded types display different clusters on the SOM map (**Figure 2a**). The clusters I and II were located in the upper part of the SOM map, whereas clusters III and IV were in the bottom areas of the SOM map.

(a)



(b)

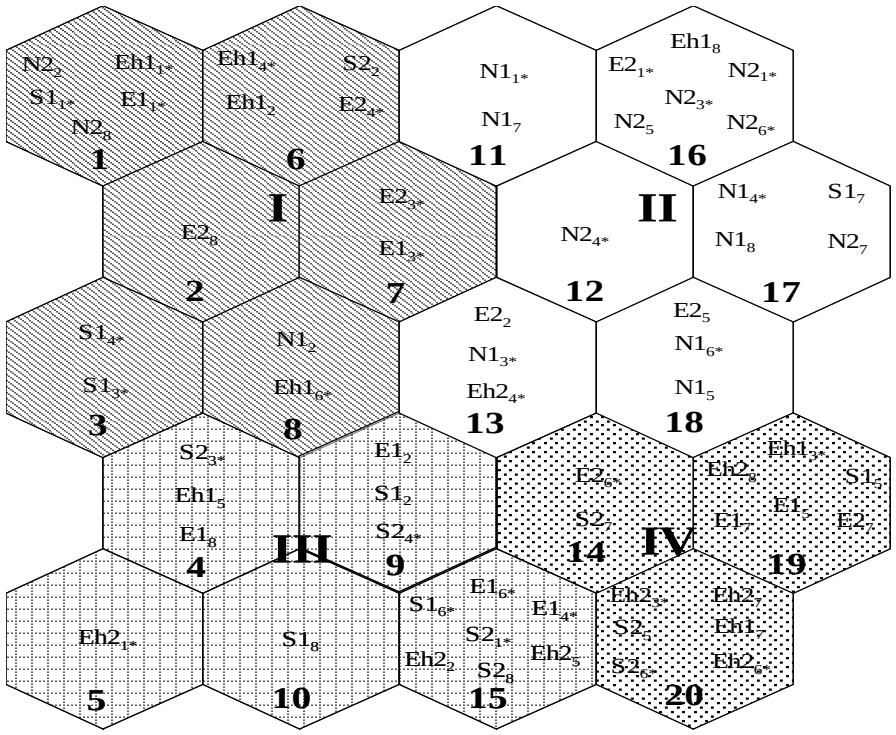
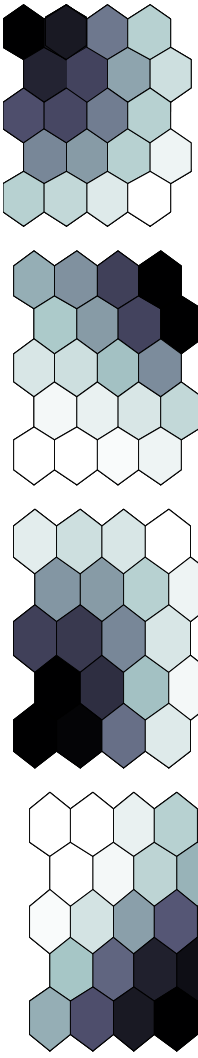


Figure 2: Classification of samples according to aquatic insect richness on the SOM map (a). Hierarchical cluster analysis with Ward algorithm with Euclidean distance measure was applied to cluster the SOM units (b). The latin numbers (I-IV) represent different clusters. The arabic numbers (1-20) represent the SOM units. Subscript numbers (1-8) represent the samples. The symbol (*) represents samples achieved in rainy season.

Figure 3 displays distribution patterns of aquatic insect taxa in each cluster defined by the SOM. Among taxa gathered in each cluster, the Indval method revealed that cluster I was mainly associated with two taxa (i.e. *Macromia* sp. and *Dytiscus* sp.) and cluster II by *Chironomus* sp. and *Tanypus* sp.. Cluster III was distinguished by *Polypedilum* sp., *Tanytarsus* sp., *Notonurus* sp. and *Thraulus* sp.. Cluster IV was mainly

characterized by Ephemeropteran taxa such as *Caenis* sp., *Dicercomyzon* sp., *Procloeon sylvicola*, *Compsoneuria njalensis* and *Cheleocloeon yolandae*.



Cluster I

Tricorythus sp., *Elmis* sp., *Riolus* sp., *Choroterpes* sp., *Ecdyonurus* sp., *Normandia* sp., *Susua* sp., ***Macromia* sp.**, ***Dytiscus* sp.**, *Ephemerythus* sp., *Machadorythus maculatus, Labiobaetis gambiae*

Cluster II

Labiobaetis gambiae, ***Chironomus* sp.**, *Cloeon* sp., *Euthraulus* sp., *Atherix* sp., *Ephoron* sp., *Paragomphus* sp., ***Tanypus* sp.**

Cluster III

***Polypedilum* sp.**, *Labiobaetis gambiae*, ***Tanytarsus* sp.**, *Ablabesmyia* sp., *Limnius* sp., *Ceratopogon* sp., *Cryptochironomus* sp., *Adenophlebiodes* sp., ***Notonurus* sp.**, *Clinotanypus claripennis, Phyllomacromia* sp., *Anopheles* sp., *Nilodorum* sp., *Dupophilus* sp., ***Thraulus* sp.**, *Anisops* sp., *Macronychus* sp., *Afritrichia* sp., *Plea* sp., *Leptocerus* sp., *Lestinogomphus angustus, Micronecta scutellaris, Orectogyrus* sp., *Stenochironomus* sp., *Triaenodes* sp., *Paragomphus* sp., *Esolus* sp., *Oulimnius* sp.

Cluster IV

Caenis* sp.**, *Labiobaetis gambiae, Cricotopus* sp., ***Dicercomyzon* sp.**, ***Procloeon sylvicola, *Nanocladius* sp., *Stictochironomus* sp., ***Compsoneuria njalensis***, *Simulium damnosum*, *Laccophilus* sp., *Coenagrion* sp., *Rhagovelia reitteri*, *Oecetis* sp., *Ceraclea* sp., *Eurymetra* sp., *Phyllogomphus aethiops, Tabanus* sp., ***Cheleocloeon yolandae***, *Cheumatopsyche* sp., *Microvelia* sp., *Orthotrichia* sp., *Paragomphus* sp.

Figure 3: Distribution patterns of insect taxa (characteristic taxa in bold) in each cluster defined by the hierarchical clustering applied on the SOM units. Dark represents high probability of occurrence, and light indicates lower probability.

The Kruskal-Wallis test showed highly significant differences in species richness between clusters ($p < 0.001$, **Figure 4**). Cluster I displayed the lowest taxonomic richness and was significantly different from clusters III and IV (Mann-Whitney test, $p < 0.05$). Cluster II comprised also fewer taxa than clusters III and IV (Mann-Whitney test, $p < 0.05$), whereas there were no significant differences (Mann-Whitney test, $p < 0.05$) between clusters I and II as well as between clusters III and IV.

Clusters I and II mainly consisted together of samples from sites (E2, Eh1, N1 and N2) which are the most disturbed by anthropogenic activities, such as agricultural and domestic activities. These sites are located close to populated areas. On the other hand, clusters III and IV gathered samples from sites (S1, S2, E1 and Eh2) which were relatively least disturbed. The test of proportion confirmed this result. Indeed, samples from both clusters I and II were significantly related to the relatively most disturbed areas (G-test, $p < 0.05$), whereas those from both cluster III and IV were significantly related to minimally disturbed areas (G-test, p

< 0.05). Concerning the seasonal factor only clusters I and III were related to it (G-test, $p < 0.05$). Most of the samples from these clusters were collected respectively in rainy and dry seasons.

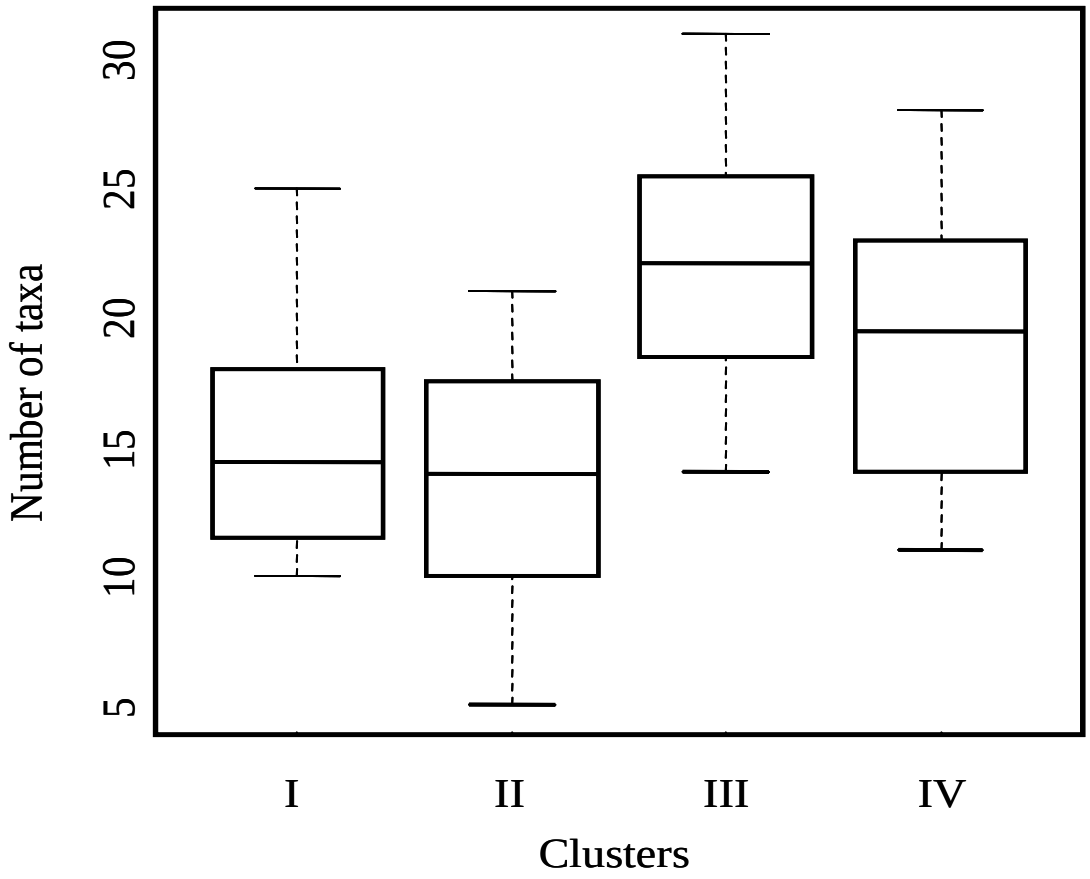


Figure 4: Box-plots showing differences in taxonomic richness between the clusters defined by the SOM. Box-plots were performed using the taxonomic richness of samples gathered in the clusters. The box is corresponding to 50% of the values, the horizontal bar in the box to the median and vertical bars to the minimum/maximum values.

The discriminant function analysis gathered original variables into three functions. As the cumulative percentage of variance explained by the first two functions was 87.9% (**Figure 5**), they were retained to display the results. The plot of the sample scores (**Figure 5**) showed a clear distinction between clusters (I and II) with lowest richness and those (III and IV) with highest diversity. However, the plot also illustrated that clusters overlapped. Despite this overlap observed between clusters, the cross-validation test confirmed the accuracy of sample clustering. Indeed, the accuracy of the four clusters (I to IV) is respectively 73.3%, 62.5%, 5% and 56.5%. Overall, most of the samples (60.9%) were classified correctly to each cluster defined by the SOM (**Table 3**).

Table 4, which summarizes the loadings of environmental variables in sample clustering, indicates that TDS and conductivity were the most strongly distinguished among the aquatic insect assemblages. The wetted width also contributed to the aquatic insect assemblage.

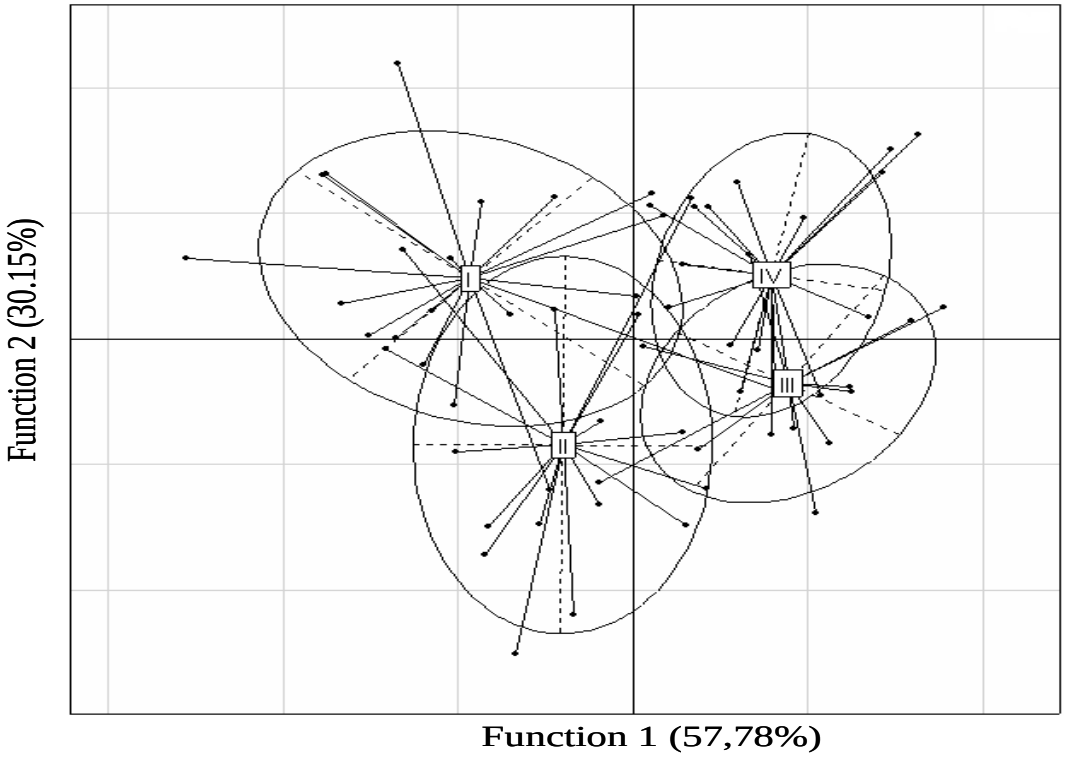


Figure 5: Plot of discriminant function scores for each of the 64 samples using the first two functions. An ellipse surrounds samples gathered in each cluster (I – IV).

Table 3: Classification results obtained by factorial discriminant analysis and by 'leave-one-out' cross-validation. The number of correctly predicted samples is shown in bold.

		Predicted cluster memberships				
Clusters	N° of samples	I	II	III	IV	Samples correctly predicted (%)
I	15	**11**	3	0	1	73.33
II	16	2	**10**	2	2	62.5
III	10	2	1	**5**	2	50
IV	23	2	2	6	**13**	56.52
Total	64	17	16	13	18	60.94

Table 4: Factorial weights of physicochemical variables on the first two functions. The most contributing variable weights were shown in bold.

Variables	Function 1	Function 2
Water temperature	-0.1377	-0.3753
pH	-0.0090	0.2362
Conductivity	**0.7109**	-0.1576
TDS	**0.8533**	-0.1446
Transparence	-0.0599	-0.3977
Dissolved oxygen	-0.6754	0.5699
Wetted width	0.1129	**0.9359**
Depth	-0.3200	-0.0105
Current velovity	-0.1913	0.4645

DISCUSSION

Traditionally, to classify samples from a given area in terms of species assemblages, stream ecologists use conventional multivariate analysis [39]. However, with non-linear data such as ecological data, SOM, a non-linear projection method, is preferable [40 - 41]. In this study, aquatic insect richness was patterned through the SOM according to the distribution similarities of each taxon. The cross-validation test showed that the accuracy of clusters was at least 50 %, indicating the relevance of the SOM in classification. The suitability of this tool is known to provide more relevant classifications and ordinations than conventional multivariate analysis due to the ability of SOM to consider rare species without overfitting bias[42 - 43].

Despite the coastal streams face low anthropogenic impact, sample clustering by the SOM can mainly be related to the impact of human activities. The samples gathered in clusters I and II are mainly from the sites E2, Eh1, N1 and N2. These sites are the most disturbed by anthropogenic activities (agricultural and domestic activities), as they are located close to areas with the most important population density. On the other hand, samples gathered in clusters III and IV are mainly from the sites S1, S2, E1 and Eh2 which are relatively exempt from disturbance. These anthropogenic disturbances may influence the pattern by increasing some environmental variables such as conductivity and total dissolved solids in these areas and reduce the aquatic insect diversity as showed by Kasangaki *et al.* [7] and Ndaruga *et al.* [10] respectively in Afromontane forest streams in Uganda and in Gatharaini Stream in Kenya.

Concerning the characteristic taxa of each cluster, our study showed that *Macromia* sp., *Dysticus* sp., *Chironomus* sp. and *Tanypus* sp. were closely associated with relatively disturbed areas. While it is difficult to explain the fidelity of the first two cited taxa, the preference of the two last ones for these areas is not surprising. According to Arimoro *et al.*[11], *Chironomus* sp. and *Tanypus* sp. are capable of resisting harsh environmental conditions. The characteristic taxa of sites minimally disturbed were Diptera (*Polypedilum* sp. and *Tanytarsus* sp.) and Ephemeroptera (*Notonurus* sp., *Thraulus* sp., *Caenis* sp., *Dicercomyzon* sp., *Procloeon syvicola*, *Compsoneuria njalensis* and *Cheleocloeon yolandae*). Except for *Polypedilum* sp. which is able to exist in disturbed waters as well as in undisturbed ones[11], the remaining taxa are known to be sentitive to water disturbance. Ogbeibu [44] was of the opinion that *Tanytarsus* sp. is incapable of resisting harsh environmental changes and could therefore be recommended as indicator taxa for freshwater stream

quality in southern Nigeria. It is recognized that Ephemeroptera are prominent in waters with high oxygen saturation, and consequently undisturbed[45- 46].

The discriminant function analysis indicated that conductivity, total dissolved solids and wetted width were the most important variables governing aquatic insect richness pattern in the four studied streams. From an ecological point of view, these results are congruent. Indeed, the runoff could introduce nutrients from agricultural fields and domestic activities to the streams[47], increasing nutrient accumulation in the streambed. This nutrient accumulation is accompanied by the increase of mineralization parameters such as conductivity and total dissolved solids and by the decrease of dissolved oxygen[48]. It could thus affect the energy flow of aquatic systems and cause the decline of local biodiversity[49-50]. In addition, the floods which coincide with the highest wetted width could increase the aquatic insect drift [51] and reduce their local diversity [52]. On the other hand, during the dry season, the reduction of spate conditions such as nutrient accumulation, flow and water velocity induces aquatic organism diversity increase[53]. These hypotheses may be the explanation of the spatial and seasonal variations of aquatic insect richness observed in this study.

It can be concluded that anthropogenic activities influenced aquatic insect richness pattern. Conductivity and total dissolved solids, along with the wetted width, are the main variables governing aquatic insect richness pattern, as they are directly related to the use of the surrounding landscape. Thus, the conservation of aquatic organisms in general, and particularly of aquatic insect diversity, is directly influence by adjacent land use and must integrate riparian landscape management.

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