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Spatial and circadian variation of aquatic insect communities in three tropical fish ponds (Natiokobadara, Korhogo, Northern Côte d'Ivoire)

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Abstract

We analysed aquatic insect distribution and their circadian variation in tropical fish ponds in a piscicultural farm used for Nile tilapia (*Oreochromis niloticus*) culture near Natiokobadara locality in the Northern Côte d'Ivoire. Among ponds of this farm, three were selected: a pond (D4) without fish, a pond (A3) stocking with 7500 fingerlings and pond (T12) of reproducers containing 680 parents. In each pond, aquatic insect samplings were undertaken every 04 hours during 24 hours in the three selected fish ponds during two cycles. Besides, ordinary samplings were done during the sampling period (July-August 2001). Overall, 25 taxa belonging to 15 families and seven orders were recorded. The pond without fish (D4) contained the higher aquatic insect richness. Heteropterans and dipterans were the mostly abundant and diverse groups. Their predominance was due to respectively *Anisops sardea* and *Chaoborus anomalus*. According the circadian variation of these two main taxa, it is likely that assemblages of these two main taxa are rather shaped by biotic factors such competition. The circadian variation of all aquatic insects collected showed that the maximum of insects was registered in daytime in the pond without fish (D4) whereas in the two others ponds (A3, T12) containing fishes the highest abundance of insects was obtained during night. The risk-of-predation hypothesis implies aquatic insects in ponds containing fish exhibit predominately during night.

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Introduction

One of the goals of freshwater ecology is to understand how communities of freshwater species are structured in space and time, and how environmental factors affect their distribution (Chlyeh *et al.*, 2006). Studies have generally been conducted in natural environments, such as rivers (e.g. Baptista *et al.*, 2001; Lods-Crozet *et al.*, 2001; Stewart *et al.*, 2002; Paavola *et al.*, 2003; Silveira *et al.*, 2006; Edia *et al.*, 2010). However, the development of aquaculture purposes creates favourable habitats (ponds) for communities of freshwater organisms. Studying such systems is interesting in several respects. For instance, the structure of habitats in ponds is generally much simpler than that of natural environments, and habitats are much more clearly delimited and more readily accessible to sampling. As a consequence, the number of species per site is lower than in natural habitats, and it should be easier to evaluate species distribution and how they are affected by environmental factors.

Several studies have considered the factors affecting macroinvertebrate distributions among ponds. For example, the presence or absence of fish or other predators (e.g., crayfish, newts) in a pond appears to be important in determining the abundance of macroinvertebrates (Mallory *et al.*, 1994; Nyström *et al.*, 1996; Smith *et al.*, 1999; Zimmer *et al.*, 2001). Water chemistry, such as pH, dissolved oxygen, etc., has also been shown to determine the distribution of macroinvertebrates among ponds (Pip, 1986; Vivar *et al.*, 1996).

Moreover, in aquatic ecosystems, the importance of macroinvertebrates and notably insects is widely recognized. According to Minshall (2003), they are primary food resources for predators such as fishes and represent sensitive indicators of overall aquatic ecosystem health. However, aquatic insects are little known in West Africa (Yaméogo *et al.*, 2004). In Ivory Coast, whereas only a few studies have focussed on lotic water macroinvertebrates (Sankaré, 1991; Lévêque *et al.*, 2003; Edia *et al.*, 2007; Edia *et al.*, 2010), there are not any studies devoted to aquatic insects in lentic ecosystems and particularly fish ponds. Moreover, concerning circadian variability of aquatic insects in Ivorian streams, to our knowledge, only Statzner *et al.* (1984) and Statzner and Mogel (1985) have worked on aquatic insect drift. So, there are not any studies were devoted to circadian variability in lentic ecosystems such as fish pond.

Our objectives were to: (1) describe aquatic insect assemblages and their composition in three fish ponds (pond without fish, pond stocking with fingerlings and pond of reproducers); (2) determine the environmental variables that best define environmental-gradient along which aquatic insect community changes and (3) assess their circadian variation in these ponds.

Materials and methods

Study area

This study was undertaken in a piscicultural farm of Natiokobadara located north of the Ivory Coast (Fig. 1). This farm, created in 1977, closes again 75 ponds and covers an area of 7.5 hectares. This farm was used for Nile tilapia (*Oreochromis niloticus*) culture. Among the ponds, only 52 fed by man-made lake nearby are functional.

Three ponds were selected for this study. They are a pond (D4) without fish, a pond (A3) stocking with 7500 fingerlings and pond (T12) of reproducers containing 680 parents. Ponds were shallow (depth < 1.5 m) and each one cover an area of 10 Ares.

Table 1 summarizes the environmental characteristics of these fish ponds.

Aquatic insect and environmental variable collection

In each pond, aquatic insect samplings were undertaken cyclically every 04 hours during 24 hours in the three selected fish ponds. The first samplings (first cycle) were done in period with moonlight, one week after the putting in water of ponds. The second cycle was undertaken in period without moonlight and three weeks after the putting in water of ponds. Besides the cyclic samplings, ordinary ones were realized in the three ponds every 3 days during the sampling period (July-August 2001).

Sampling was done by mean of hand net (mesh size: 250µm). 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. The samples were fixed in 10% formaldehyde. In the laboratory, specimens were sorted and identified to the lowest taxonomic level possible by means of the keys in Déjoux *et al.* (1981), Barber-James and Lugo-Ortiz (2003), de Moor and Scott (2003) and Samways andWilmot (2003).

During each sampling period at each sampling site, water temperature, pH, conductivity and total dissolved solids were measured with portable sensors. Secchi disk transparency was measured with a standard 20-cm-diameter Secchi disk.

Data analysis

Aquatic insect abundance was obtained by counting all individuals per taxon and expressing the results as numbers per sample. Total richness (S) was measured for each sampling time at each site.

In order to determine the spatial distribution of aquatic insects, factorial component analysis (FCA) was carried out with the matrix of total number of aquatic insects per site at each sampling period (with and without moonlight). Analyses were conducted using the R package (Ihaka and Gentleman, 1996).

To explore the response of macroinvertebrates, a Principal Component Aanalysis (PCA) and a Canonical Analysis (CA) on abundance data were performed, and these preliminary analyses showed that aquatic insect variation was better described by unimodal models than by linear models. A Canonical Correspondence Analysis (CCA) was carried out using CANOCO 4.5 software (ter Braak and Smilauer, 2002). According to these authors, this method expresses the main relations between species and environmental variables by combining ordination and regression.

All data were $\log_{10}(x + 1)$ transformed to achieve the condition of normality and homocedasticity of the data. A Monte Carlo permutation test (Jckel, 1986) was used to assess the significance of the canonical axes extracted.

Results

Taxonomic composition and spatial distribution

A total of 25 taxa of aquatic insects belonging to 15 families and seven orders were recorded (Table 2). The fish pond D4 contained the higher aquatic insect richness (18 taxa) whereas the lower (12 taxa) was observed in T12. The three fish ponds have seven taxa (*Centroptilum* sp., *Eurymetra* sp., *Anisops sardea*, *Chaoborus anomalus*, *Aedes* sp., *Ablabesmiya dusoleili* and *Polypedilum fuscipenne*) in common.

The richest orders of insects were Diptera (13 taxa) followed by Heteroptera (6 taxa). These two orders were the most abundant at each pond (Fig. 2). The high individual abundance (456 individuals) of dipterans was observed in fish pond T12 during the sampling period with moonlight (T12_1) whereas the low one (107 individuals) was registered in the fish pond D4 at the period without moonlight (D4_2). Concerning the heteropterans, their individual number was ranged between 15 individuals in fish pond D4 during the sampling period with moonlight (D4_1) and 774 individuals in the same pond but at the period without moonlight (D4_2).

The high abundance of Heteroptera and Diptera was due to the predominance of respectively *Anisops sardea* (Notonectidae) and *Chaoborus anomalus* (Chironomidae) (Fig. 3) in the studied fish ponds at each sampling period. Note that *Chaoborus anomalus* was most abundant at the first cycle (with moonlight) whereas *Anisops sardea* was most abundant at the second cycle (without moonlight).

Table 1. Geographical positions and range of environmental variables of the three study fish ponds

	Fish ponds		
	D4	A3	T12
Geographical	09° 29 ' 07" N	09° 29' 17" N	09° 29' 27" N
positions	05° 37 ' 01" W	05° 37' 01" W	05° 37' 03" W
Temperature (°C)	23 - 29.3	26.3 - 30.1	26 - 30.2
pH	4.4 - 9.6	6.1 - 7.5	6.1 - 9.1
Conductivity (µS.cm^{-1})	25 - 36.6	26 - 40	19 - 22
Total Disolved Solid (mg.L^{-1})	20 - 26	18 - 28	14 - 15
Transparency (cm)	25 - 30	19 - 26	16 - 24

Figure 4 shows sample ordination by multivariate analysis (FCA). Axis1 and axis 2 explain 78.7 % and 15.4 % of the variance, respectively (Fig. 4a). This ordination displays two clusters (I and II) according to the Axis 1 (Fig. 4b). This axis discriminates samples taken at the period with moonlight (first cycle) towards the negative part of the graph (cluster I) and those taken at the period without moonlight (second cycle) towards the positive part (cluster II): this indicates a periodical pattern. As it was shown by figure 3, the samples gathered in cluster I (i.e. at the period with moonlight) were mainly dominated by *Chaoborus anomalus* and those of cluster II (i.e. at the period with moonlight) were mainly dominated by *Anisops sardea*.

Environmental relationships

The results of the CCA ordination for 25 aquatic insect taxa and five environmental variables showed that 35.1% of the variance in taxa abundance was accounted by the first four ordination axes (Table 3). CCA resulted in a significant model as was shown by the Monte Carlo Test.

From the CCA ordination diagram of aquatic insects in relation to water properties (Fig. 5), one may deduce that the first principal component contrasts water temperature with all the other environmental variables (Conductivity, TDS, pH and transparency). The pH and the transparency are most strongly and positively correlated respectively with axis 1 and axis 2. They were the most influential water variables that dictated the distribution of aquatic insect taxa such as *Nilodorum fractilobus* and *Ablabesmyia dusoleili* (both Diptera, Chironomidae). Water temperature is most strongly and negatively correlated with axis 2. It influenced the distribution of *Procladius* sp. (Diptera, Chironomidae) and *Ranatra parvipes* (Heteroptera, Nepidae). Note that some taxa such as *Anisops sardea* and *Chaoborus anomalus* seemed lest influenced by environmental variables as they were located close to the origin of the axes.

Circadian variations

During the first cycle (Fig. 6a), the circadian variations of aquatic insects showed that the high total number of individuals (169 individuals) was registered during daytime around 10h in pond D4 (without fish). In the ponds of fingerlings (A3) and reproducers (T12), total individual number was high respectively during the night (22h, 106 individuals) and at the beginning of the night (18h, 302 individuals). During this cycle, in the three ponds, the number of individuals of *Chaoborus anomalus* was higher than that of *Anisops sardea*.

Table 2. List of the aquatic insect taxa found in the three study fish ponds.

				Fish ponds		
Order	Family	Taxon	Acronym	D4	A3	T12
Ephemeroptera	Baetidae	*Centroptilum* sp.	Cen	*	*	*
	Machadorythidae	*Machadorythus palanquin*	Map		*	*
Odonata	Libellulidae	*Pantala flavencens*	Paf	*		
Heteroptera	Gerridae	*Eurymetra* sp.	Eur	*	*	*
	Corixidae	*Micronecta* sp.	Mic	*		*
		Micronecta soutellaris	Mis	*		
	Notonectidae	*Anisops sardea*	Ans	*	*	*
	Nepidae	*Enithares* sp.	Eni		*	
		Ranatra parvipes	Rap			*
Lepidoptera	Pyralidae		Pyr	*		
Coleoptera	Hydrophylidae	*Enochrus* sp.	Eno		*	*
Trichoptera	Ecnomidae	*Ecnomus* sp.	Ecn	*	*	
Diptera	Chaoboridae	*Chaoborus anomalus*	Cha	*	*	*
	Ceratopogonidae	*Ceratopogon* sp.	Cer	*		
	Culicidae	*Aedes* sp.	Aed	*	*	*
	Chironomidae	*Ablabesmiya dusoleili*	Abd	*	*	*
		Ablabesmiya pictipes	Abp			*
		Chironomus formosipennis	Chf	*		
		Nilodorum fractilobus	Nif	*		
		Polypedilum fuscipenne	Pof	*	*	*
		Procladius sp.	Pro			*
		Stictochironomus caffrarus	Stc	*		
		Stictochironomus puripennis	Stp	*		
		Tanypus lacustris	Tal	*		
	Psychodidae		Psy		*	

Table 3. Summary of the canonical correspondence analysis (CCA) of aquatic insect and environmental data from the three study fish ponds.

Axes	**1**	**2**	**3**	**4**	**Total inertia**
Eigenvalues	0.346	0.222	0.2	0.118	0.894
Species-environment correlations	0.916	0.862	0.884	0.766	
Cumulative percentage variance					
of species data	13.1	22.6	30.1	35.1	
of species-environment correlation	22.4	43	58.9	71.1	
Test of significance:					
Axis1: F-ratio = 1.427, p<0.005					
All canonical axes: F-ratio =1.201, p< 0.005					

Concerning the second cycle (Fig. 6b), in pond D4 (without fish), the maximum of individuals (260) was also obtained in daytime around 14h. In the ponds containing fishes (A3 and T12), aquatic insect individuals sampled was maximum during night respectively around 22h (324 individuals) and 02h (183 individuals). Contrary to the first cycle, during this cycle, the highest total number of individuals coincides with the highest abundance of *Anisops sardea*, excepted in fish pond T12. In this pond, the highest total number of individuals coincides with that of *Chaoborus anomalus*.

Discussion

Aquatic insect assemblages from the three fish ponds were characterized by the presence of Ephemeroptera, Odonata, Heteroptera, Lepidoptera, Coleoptera, Tichoptera and Diptera. Heteropterans and dipterans were the mostly abundant and diverse groups. So, these two orders were predominant in these artificial ponds as it was showed by Della Bella *et al.* (2005) and Apinda-Legnouo (2007) in ponds respectively in Italy and South-Africa. Similarly, the community composition matches previous studies that also reported Diptera and Heteroptera as the best-represented insect orders (Fischer *et al.*, 2000; Boix *et al.*, 2001). Considering these two orders, maximum richness tends to concentrate in a few families, namely: Corixidae and Nepidae among heteropterans and Chrironomidae among dipterans.

Quantitatively, the predominance of heteropterans and dipterans was due to respectively those of *Anisops sardea* and *Chaoborus anomalus*. *Chaoborus anomalus* was most abundant in the first cycle. The second cycle was predominated by *Anisops sardea*. Moreover, the circadian variation of these two main taxa showed that when the abundance of *Anisops sardea* was high that of *Chaoborus anomalus* was low and vice versa. Furthermore, CCA showed also that the distribution of these two main taxa seemed lest influenced by environmental variables. It is likely that assemblages of these two main taxa are rather shaped by biotic factors such competition. Indeed, it is known that *Chaoborus* are often considered as opportunistic eaters, as they eat both copepods and cladocerans even if they prefer copepods to cladocerans (Pastorok, 1980). Corcerning *Anisops sardea*, it is known that they are predators. In addition, Eitam *et al.* (2002) showed that the presence of *Anisops sardea* in artificial pool reduce the taxon richness by consuming cladocerans. Thus, *Anisops sardea* structures the community, both by a behavioral response of prey to its presence and by consumption of prey.

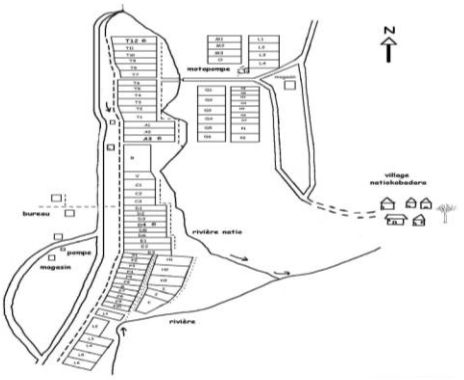

Fig. 1. Location of the study area showing the three fish ponds studied.

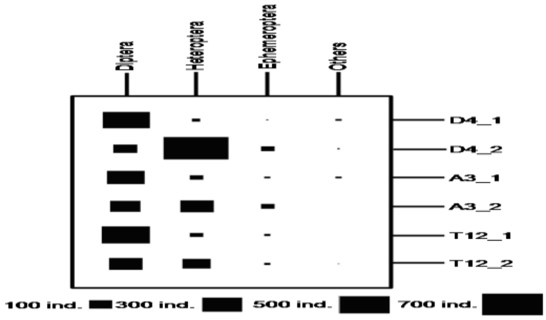

Fig. 2. Proportions in terms of taxa number of aquatic insect orders collected in three fish ponds (A3, D4, T12). 1: first cycle; 2: second cycle.

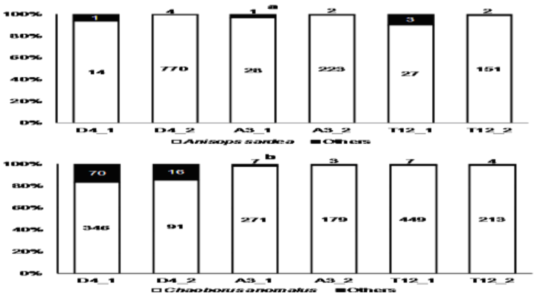

Fig. 3. Composition of heteropterans (a) and dipterans (b) in the three fish ponds (D4, A3, T12). 1: first cycle; 2: second cycle.

Overall, the circadian variations of all aquatic insects collected in the three ponds showed the maximum of insects was registered in daytime in the pond without fish (D4) whereas in the two others ponds containing fishes the highest abundance of insects was obtained during night. This difference in circadian variations of aquatic insects in the two kinds of ponds could be explained by the presence of fish (*Oreochromis niloticus*). Indeed, Richter *et al.* (2004) indicated in Philippines that the feeding activity of *Oreochromis niloticus* is diurnal. Similarly, studies undertaken by Bamba *et al.* (2007) in Côte d'Ivoire conclude that *Oreochromis niloticus* have diurnal diel feeding periodicity. So, this fish prey actively in daytime. Consequently, the risk-of-predation hypothesis (Flecker, 1992) implies aquatic insects in ponds containing fish exhibit predominately during night. In addition, it was found during this study that the circadian evolution of aquatic insects showed the same trend as during the two cycles (with moonlight and without moonlight). Thus, there is no effect of moonlight on the circadian variation of aquatic insects in the studied ponds as found Statzner and Mogel (1985) in some rivers of Côte d'Ivoire.

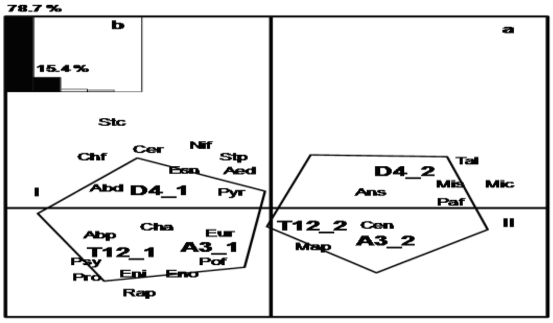

Fig. 4. Factorial Component Analysis (FCA) run on taxon presence/absence in the three fish ponds (D4, A3, T12). (a) Distribution of sampling sites and taxa on the F1 x F2 plane. (b) Histogram of eigenvalues. 1 and 2 represent first and second cycles. Polygons represent clusters (I and II). See Table 2 for taxon acronyms.

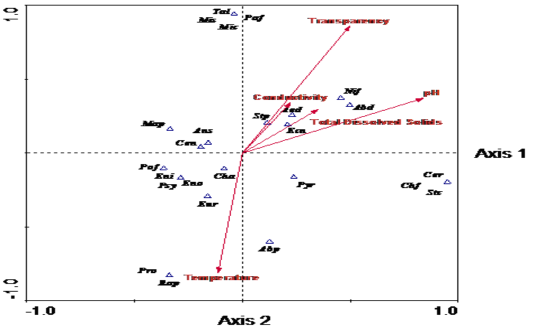

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Fig. 5. Canonical correspondence analysis (CCA) diagram of aquatic insect taxa in relation to environmental variables (arrows) measured. See Table 2 for taxon acronyms.

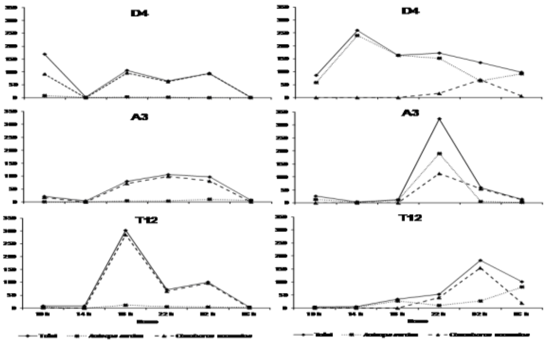

Fig. 6. Circadian variations of aquatic insect abundance in the three fish ponds studied during the first cycle (a) and the second cycle (b).

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