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Diversity and distribution of aquatic insects in Koko and Natiokobadara dam lakes in Korhogo (North Côte d'Ivoire)

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Abstract
The study aims to survey the diversity and distribution of the aquatic insects of two dam lake in the northern region of Côte d'Ivoire. Aquatic insect were collected using a kick-net during three months: from January 2020 to March 2020. Environmental variables such as transparency, temperature, pH, dissolved oxygen and conductivity were measured *in situ* between 08.00 am and 10.00 am. Twenty-seven and 45 taxa were recorded in Koko and Natiokobadara lakes respectively. These taxa belonged to 23 families and 6 orders. Insects belonging to the orders Heteroptera dominated quantitatively and qualitatively the settlement. Koko dam lake registered the highest values of Shannon-Wiener index and evenness and the lowest value of Margalef richness index. The distribution of the main aquatic insects responsible for the differences between the Natiokobadara and Koko sites was visualized using correspondance analysis. The dam lake can be considered as a refuge for aquatic insects.

Keywords: Aquatic insect, dam lake, diversity, distribution, Côte d'Ivoire

Introduction
In Côte d'Ivoire, the construction of several hundred small dams in the north of the country was at the center of a strategy adopted following the droughts episodes of the 1970s and 1980s. Thus, in the greater northern region, 298 dams were built [1]. Koko and Natiokobadara lakes are part of the lakes created in the city of korhogo. They were built for water supply and irrigation of rice cultivation. Dams are artificially constructed water reservoirs. They are either isolated (built in a wetland at the bottom of the valley) or built across the channel of a river. Their importance as refuges of aquatic biodiversity is recognized [2, 3]. Lakes are part of the freshwater habitats that harbour a greater biodiversity of insects. Although aquatic insects represent only 3 to 5% of all insect species, they are taxonomically diverse [4] and play an essential role in ecosystem stability and maintenance, particularly in nutrient dynamics. Aquatic insects, a group of Arthropods, live their life cycle in water bodies and are found in or on the surface of the lentic or lotic waters [5]. They are considered as a very good indicator of water quality because of their wide range of environmental disturbance tolerant levels [6]. In aquatic habitats, insects are the nutritious fauna for many organisms including fish, amphibians and invertebrates [7]. In Côte d'Ivoire, aquatic insects have been the subject of a few studies in a lake environment [8, 11] in the south and center part of the country. However, very little literature shows the diversity of aquatic insects in the northern zone [12]. The study aim to survey the diversity and distribution of the aquatic insects.

Materials and Methods
Study area and sampling sites
Koko and Natiokobadara dam lakes are located in the northern of Côte d'Ivoire (Poro region) in the town of Korhogo. Koko lake is between latitude 09 ° 28'19.0 "N and longitude 05 ° 30'50.4" W with an average altitude of 377m, while Natiokobadara lake extends between latitude 09 ° 29'38.5 " N and longitude 05 ° 37'13.6" W with an average altitude of 331m. The rainfall varies from 1,300 mm to 1,400 mm per year. Three sampling sites were selected in Koko dam lake (K1 to K3) and three others in Natiokobadara dam lake (N1 to N3) (Figure 1). These sites were sampled during three sampling campaigns from January 2020 to March 2020.

Data collection

Samples were collected each month during three campaigns at each sampling site. On each sampling campaign, environmental variables such as transparency, temperature, pH, dissolved oxygen and conductivity were measured *in situ* between 08.00 am and 10.00 am. Aquatic insects were sampled using a Kick- net (400 µm mesh). On each site, 6 net strokes were sampled. Samples were collected in labeled pill boxes and fixed with 10% formalin. In the laboratory, the collected material was washed and the organisms were identified until the less possible taxonomic level using identification keys of [13, 14].

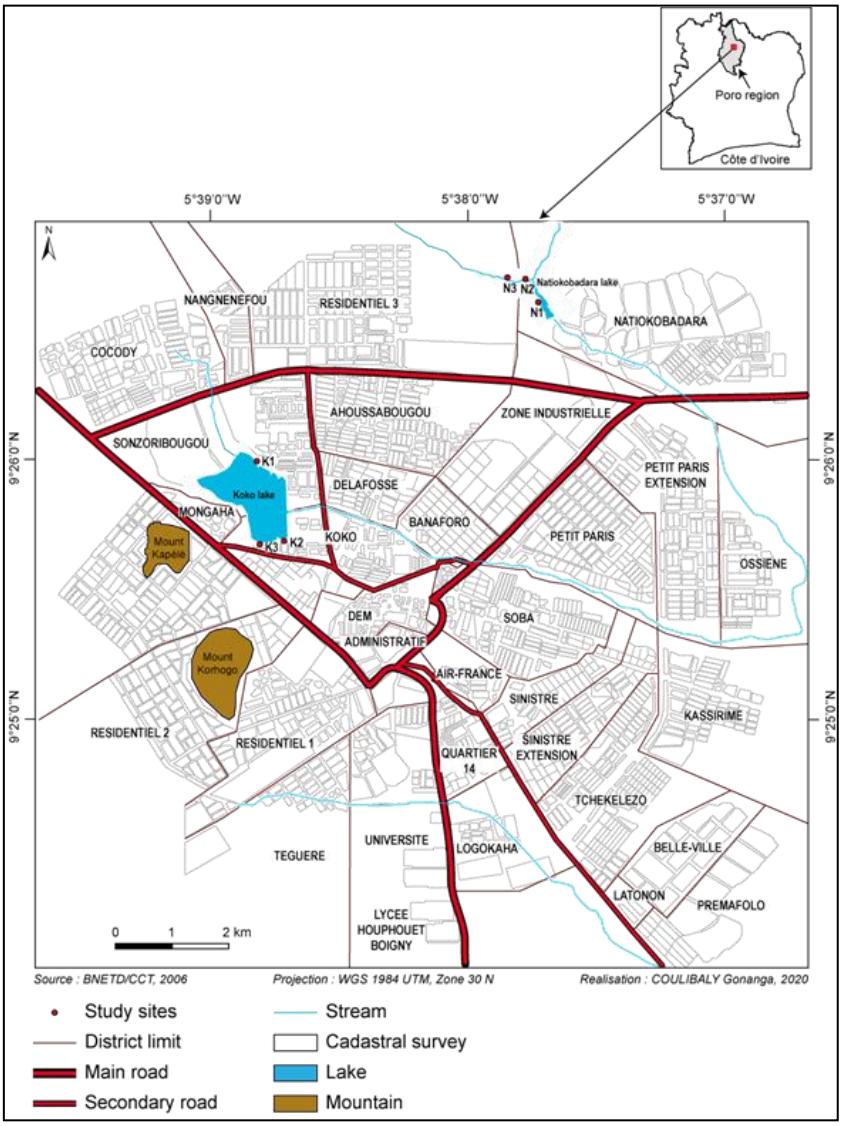

Fig 1: Location of sampling sites

Data analysis

For ecological indices reflecting the population features we calculated the diversity indices such as Shannon-Weaver index and Pielou'evenness. Data were analysed using appropriate statistical tools. Prior further analysis, the normality test was carried out on the diversity indices and environmental variables using Kolmogorov-Smirnov test. This test was carried out by using the Statistica software (version 7.1). The different data are not normally distributed. Therefore, non-parametric Kruskal Wallis Test ($P< 0.05$) was used to compare data between the months. Ecological indices were calculated using the PAST 1.0 software. The PRIMER 5.0 software (Plymouth Marine Laboratory) [15] was used to calculate Bray-Curtis (dis)similarities between all samples. Samples were grouped together concordantly with a spatial scale: the different sampling locations (Koko 1/Koko 2/Koko 3/Natiokobadara 1/Natiokobadara 2 /Natiokobadara 3). One-way Analysis of Similarities (ANOSIM) was carried out to test for significant differences in the aquatic insect community structure between the two dam lakes. For that the sites are grouped to Koko Dam Lake and Natiokobadara Dam Lake. Similarity of Percentages (SIMPER) was used to investigate which taxa were responsible for these differences. A correspondance analysis was carried out with the main taxa responsible for the asymmetry between the two dam lakes. This analysis allowed the distribution of these main taxa to be determined. K-dominance curves were plotted for the comparison of species composition at the sites.

Results and Discussion

Environmental variables

The monthly variation in the values of the environmental variables is presented by Table 1. Environmental variables such temperature and pH, exhibit a significant difference between the months. The highest value of temperature was observed in March at Natiokobadara 3 (31.1°C) and the lowest value was registered in January at Natiokobadara 1 (18.6°C). Koko 1 had the lowest value of pH during February, while the highest value of this parameter was recorded at Natiokobadara 1 during March. Electrical conductivity was the highest at Natiokobadara 2 (272.2 µS·cm^{-1}) in February and the lowest at Natiokobadara 1 (32.9 µS·cm^{-1}) during January. Koko 2 registered the highest value of transparency (0.64 cm), while this variable was lowest at Natiokobadara 1 and Natiokobadara 3 (0.24 cm) during January and March respectively. Dissolved oxygen fluctuated between 3.99 mg/L (Natiokobadara 1) and 6.84 (Koko 2) during March and January respectively.

Table 1: Monthly variation of environmental variables recorded in the Koko and Natiokobadara dam lakes. K1= Koko 1, K2=Koko 2 et K3=Koko 3: N1=Natiokobadara 1, N2=Natiokobadara 2 et N3=Natiokobadara 3.

Months	Variables	Sites					
		K1	K2	K3	N1	N2	N3
January	Temperature	23.77	25.8	29.3	18.6	20.8	21.8
February	(°C)	27.1	27.6	28.8	22.9	25.9	26
March		30	31.9	30.7	25.3	29.7	31.1
January	pH	7.22	7.73	6.73	7.22	6.85	7.02
February		6.71	6.89	6.96	7.05	7.02	7.19
March		7.22	7.42	7.04	7.79	6.98	7.49
January	Conductivity	136.5	143.7	142.5	32.9	174.2	190.4
February	(µS/cm)	164.4	167.9	172.5	65.6	272.2	228.27
March		197.3	202.2	194.2	103.1	148.5	242.7
January	Transparency	0.45	0.56	0.49	0.24	0.29	0.33
February	(cm)	0.37	0.64	0.43	0.27	0.32	0.3
March		0.54	0.48	0.51	0.29	0.31	0.24
January	Dissolved	5.08	6.84	6.58	4.56	4.24	4.96
February	Oxygen (mg/L)	5.78	6.75	6.43	4.64	4.89	5.01
March		5.24	6.72	6.51	3.99	4.1	4.01

Aquatic insect taxonomic composition

A total of 55 aquatic insect taxa belonging to 23 families and 6 orders were harvested (Table 2). Twenty-seven and 45 taxa were recorded in Koko and Natiokobadara lakes respectively. The taxonomic richness of Koko and natiokobadara dam Lake was lower than those obtained in other lakes in Côte d'Ivoire [8, 11, 16]. These authors recorded respectively 68, 74 taxa and 123 taxa. The low specific richness recorded in this study could be attributed to various factors. First, our sampling was conducted for only three months, whereas the above-mentioned studies covered a sampling year. The low richness observed could also be due to the disturbance of the Koko Dam Lake sites by human activities such as agriculture and fishing. Indeed, as pointed out by [17] habitat destruction may lead to a reduction in aquatic macroinvertebrate diversity. Insects belonging to the orders Heteroptera (30.90%) and Odonata (23.63%) showed greater species richness, followed by those belonging to the orders Coleoptera (21.81%) and Diptera (16.36%), respectively (Table 3). However, the abundance of different groups of insects did not follow the same trend. Organisms of the order Heteroptera dominated the settlement (54.05%), followed by the species Diptera (24.41%), Coleoptera (9.07%) and Odonata (6.26%), respectively. At the family level, the members of the Libelullidae (Odonata) were richer in species (8 species), followed by Chironomidae (Diptera) with 7 species and that of Notonectidae was the most individualized family representing 29.80% of the total individuals registered. This family was followed by that of Chironomidae (294 individuals) accounting for 23.61% of the total individuals recorded in this study. The dominance of Libellulidae in species richness has been observed in similar studies [18-20]. Kalkman *et al.* [21] reported that Libellulidae belong to the four largest families of the Odonate order. Libellulidae are one of the two largest families in the world and dominate the fauna of stagnant water dragonflies on all continents. A high percentage of species in this family have a wide range [22]. Libellulidae are the most diverse and numerous group of Odonates [23] with more than 1000 species in about 140 genera [24] that breed mainly in stagnant water or lentic habitats [25].

Table 2: List of aquatic insect taxa registerd in Koko and Natiokobadara dam lake and their occurence. K1= Koko 1, K2=Koko 2 et K3=Koko 3: N1=Natiokobadara 1, N2=Natiokobadara 2 et N3=Natiokobadara 3.

Orders	Families	Taxa	Sites					
			K1	K2	K3	N1	N2	N3
		Ranatra linearis			**	***	***	***
	Nepidae	*Laccotrephes ater*		**		***	***	***
		Nepa cinerea						**
		Enithares sp.				**	**	
	Notonectidae	*Anisops sardea*	***	***	***	***	***	***
		Anisops sp.	**	***	**	**	**	
	Belostomatidae	*Diplonychus* sp.	***	***	***	***	***	***
		Limnogeton fieberi						**
Heteroptera		*Limnogonus chopardi*			**	**	**	***
	Gerridae	*Eurymetra* sp.	***	**	**	**		
		Gerisella sp.		**	**	***	**	**
	Veliidae	Veliidae			**			
		Microvelia sp.					**	
	Mesoveliidae	*Mesovelia* sp.					**	

	Corixidae	*Micronecta* sp.				***	**	***
		Micronecta scutellaris						**
	Naucoridae	*Naucoris cimicoides*				***		
Ephemeroptera	Baetidae	*Cloeon gambiae*		**		**		**
		Cloeon smaeleni				***	**	
		Pseudocentroptilum sp				***		
Odonata	Libellulidae	*Orthetrum* sp.	**			***	***	**
		Brachythemis leucosticta	***	***	**			
		Brachythemis lacustris	**	***	***			
		Palpopleura lucia				**		**
		Palpopleura jacunda				**	***	
		Bradinopyga strachani	**		**			
		Parazyxomma flavicans	**		**			
		Crocothemis erythraea					**	
	Aeshnidae	*Anax tristis*				**		
		Gynacantha manderica					**	
	Coenagrionidae	*Pseudagrion massaicum*	**	**	**	***	***	**
		Pseudagrion citricola				**		
	Gomphidae	*Ictinogomphus* sp.					**	**
Coleoptera	Dytiscidae	*Cybister tripunctatus*				**	***	
		Hydrocoptus simplex				**		
		Laccophilus sp.				**		***
		Enochrus sp.				***		**
	Hydrophilidae	*Amphiops* sp.				***	***	**
		Hydrobiinae				**		**
		Hydrophilidae					**	
	Gyrinidae	*Dineutus* sp.				***	***	***
		Aulonogyrus sp.				**		
	Spercheidae	*Spercheus* sp.				**		
	Haliplidae	*Haliplus* sp.		**	**			
	Curculionidae	Curculionidae	**					
Diptera	Chironomidae	*Chironomus imicola*	***		**	**	***	***
		Cryptochironomus sp	***	**	**		***	
		Ablabesmyia dusoleili	**		**			
		Nilodorum fractilobus	**		***	**		
		Nilodorum brevipalpis	***	***	***		**	
		Tanypus fuscus	**		**			
		Clinotanypus claripennis			**			
	Culicidae	*Culex fatigans*		**		**		
	Tabanidae	*Tabanus* sp.	**					**
Lepidoptera	Crambidae	Crambidae				***	***	**

***Very frequent taxa (FO>50%); **Frequent taxa (25%≤FO≤50%); *Rare taxa (FO<25%).

Table 3: Taxa richness and aquatic insects diversity indices in Koko and Natiokobadara dam lakes.

Variables	Koko	Natiokobadara
Taxa richness	27	45
Abundance	256	989
Shannon-Wiener (H')	2.52	2.42
Margalef richness	4.69	6.38
Pielou Evenness	0.76	0.63

Frequency of Occurrence

Anisops sardea, *Diplonychus* sp. and *Pseudagrion massaicum* were the most common taxa found at all the sampling sites (Table 2). In Koko 1, 7 taxa (*Anisops sardea*, *Diplonychus* sp., *Eurymetra* sp., *Brachythemis leucosticta*, *Chironomus imicola*, *Cryptochironomus* sp. and *Nilodorum brevipalpis*) were very frequent and 11 taxa were frequent. Six very frequent taxa (*Anisops sardea*, *Anisops* sp, *Diplonychus* sp., *Brachythemis leucosticta*, *Brachythemis lacustris* and *Nilodorum brevipalpis*) and 8 frequent were recorded in Koko 2. At Koko 3, 5 taxa (*Anisops sardea*, *Diplonychus* sp., *Brachythemis lacustris*, *Nilodorum fractilobus* and *Nilodorum brevipalpis*) were very frequent and 16 taxa were frequent, At Natiokobadara 1, 14 taxa (*Ranatra linearis*, *Laccotrephes ater*, *Anisops sardea*, *Diplonychus* sp, *Gerisella sp*, *Micronecta* sp., *Naucoris cimicoides*, *Cloeon smaeleni*, *Pseudocentroptilum*, *Orthetrum* sp., *Pseudagrion massaicum*, *Enochrus* sp., *Amphiops* sp., *Dineutus* sp.) were very frequent and 19 taxa were frequent. Twelve taxa (*Ranatra linearis*, *Laccotrephes ater*, *Anisops sardea*, *Diplonychus* sp., *Orthetrum* sp., *Palpopleura jacunda*, *Pseudagrion massaicum*, *Cybister tripunctatus*, *Amphiops* sp., *Dineutus* sp., *Chironomus imicola*, *Cryptochironomus* sp.) were very frequent and 14 taxa were frequent at Natiokobadara 2. Natiokobadara 3 registerd, 9 very frequent taxa (*Ranatra linearis*, *Laccotrephes ater*, *Anisops sardea*, *Diplonychus* sp, *Limnogonus chopardi*, *Micronecta* sp., *Laccophilus* sp., *Dineutus* sp., *Chironomus imicola*) and 14 frequent taxa. *Anisops sardea* and *Diplonychus* sp. were very frequent (FO≥50%) at all the sampling sites. *Anisops sardea* has been recognized as a frequent taxon in previous work [26].

Diversity indices

Aquatic insect diversity indices showed a lower Shannon-Wiener diversity index and Pielou Evenness index at Natiokobadara lake of 2.42 and 0.63, respectively, compared to Koko lake (Table 3). However, Margalef richness index was found higher at Natiokobadara lake than that of Koko lake. In our study, aquatic insect richness and diversity differed between lake and sampling sites. Generally koko lake appears to record low taxon richness and abundance as well as high diversity index values. In fact, communities of higher species diversity are more stable than communities that are less diverse. Xu *et al.* [27] found that system with high species diversity is more likely to have some species to decompensate the negative effects on a certain species due to environmental fluctuations. The Specific Diversity Index (Shannon-Weaver Index) is high when the taxonomic richness is important and the distribution of individuals between taxa is balanced. A less diversified settlement with dominant species results in low values of this index [28]. The values of the Shannon-Weaver index recorded are high. Thus, these two lakes present a well-diversified population where several taxa are well represented numerically. In Koko dam lake, the Shannon-Weaver index and equitability are higher than those of Natiokobadara. This would be due to a better distribution of taxa in this lake.

Species composition similarity between lakes

The different sampling sites were clustered into two major groups (Figure 2), based on Bray-Curtis single linkage similarity analysis. The sampling sites of Natiokobadara dam lake formed the first group and the remaining 3 sites of Koko dam lake formed the second group. In the first group, the sampling sites of Natiokobadara 1 differed from other sampling sites. In the second group, the site of Koko 3 differed from the others. The nMDS (stress of 0.00) confirms this arrangement insofar as, where the sites Koko 1 and Koko 2 were intertwine (Figure 3). The first group was mainly clustered with higher taxa distribution ranging from 23 to 33 for each site. The second group of clusters was characterized by low species diversity which ranged from 14 to 21 taxa compared to the first group. To verify the similarity between the different lakes, an analysis of similarities (ANOSIM) was carried out. This analysis calculated significant differences between insect community assemblages from the Koko dam and the Natiokobadara dam, regardless of the location of the sampling sites. The absolute value of R calculated (R = 0.679, p = 0.0001) is between 0.5 and 0.75, so the groups represented on the one hand by the Koko sites and on the other hand by the Natiokobadara sites are different [15]. The percentage of similarity (SIMPER) was used to show the species responsible for the differences between the Koko and Natiokobadara dam sites. The taxa responsible for these differences are presented in Table 4. The average asymmetry for these two habitats is 79.69%. Thirty-seven taxa were responsible for this asymmetry. *Anisops sardea*, *Tanypus fuscus*, *Diplonychus* sp., *Amphiops* sp., *Chironomus imicola* and *Eurymetra* sp. are among the taxa responsible for the asymmetry between the two lakes.

These taxa have been reported in other studies where they have contributed to the difference between the composition and abundance of taxa between different sites [26].

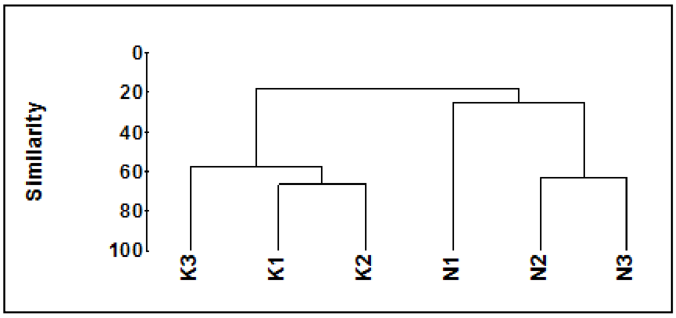

Fig 2: Bray-Curtis similarity dendrogram based on the abundance of aquatic insects at the different sites.

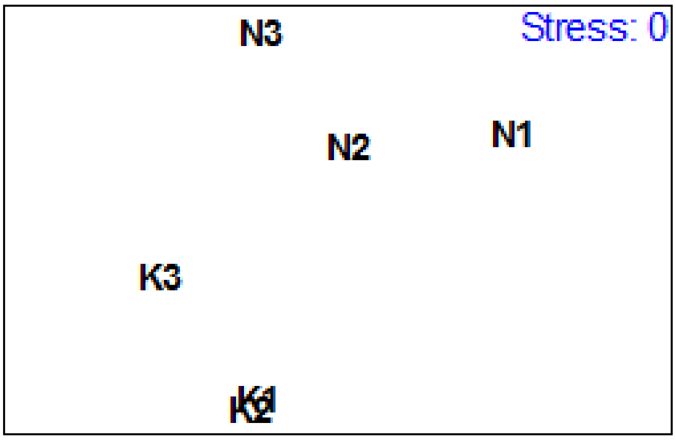

Fig 3: nMDS based on the abundance of insects showing the disposition of different sites.

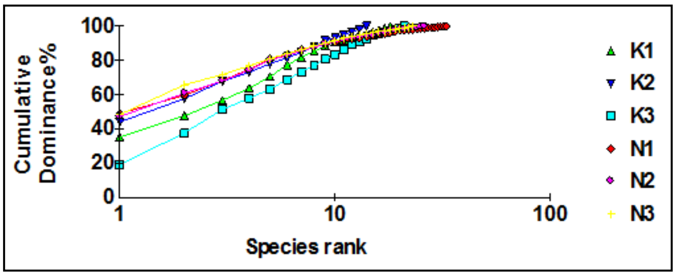

Fig 4: K-dominance curves of the different study sites.

Table 4: List of discriminant species for comparisons of similarity between the two dams, Co%: percentage of mean asymmetry due to species and Cu%: cumulative contribution of species to the asymmetry between the two dam lakes.

Taxa	Co. %	Cu. %
Chironomus imicola	5.68	5.68
Dineutus sp.	5.50	11.18
Ranatra linearis	5.46	16.64
Laccotrephes ater	5.24	21.88
Anisops sardea	4.67	26.55
Micronecta sp.	3.86	30.42
Pseudagrion massaicum	3.51	33.92
Diplonychus sp.	3.40	37.32
Crambidae	3.38	40.70
Brachythemis lacustris	3.12	43.82
Nilodorum brevipalpis	2.98	46.80
Eurymetra sp.	2.98	49.78
Anisops sp.	2.93	52.71
Brachythemis leucosticta	2.90	55.61
Orthetrum sp.	2.79	58.40
Amphiops sp.	2.78	61.18
Gerisella sp.	2.42	63.61
Cryptochironomus sp	2.40	66.01
Limnogonus chopardi	2.39	68.40
Enochrus sp.	1.88	70.27
Laccophilus sp.	1.68	71.95
Nilodorum fractilobus	1.67	73.62
Cloeon smaeleni	1.56	75.19
Cybister tripunctatus	1.51	76.70
Palpopleura jacunda	1.34	78.04
Hydrobiinae	1.32	79.36
Tabanus sp.	1.23	81.88
Cloeon gambiae	1.23	81.88
Bradinopyga strachani	1.09	82.97
Ictinogomphus sp.	1.03	84.00
Palpopleura lucia	1.01	85.01
Naucoris cimicoides	1.00	86.01
Pseudocentroptilum	0.93	86.95
Haliplus sp.	0.92	87.86
Parazyxomma flavicans	0.90	88.76
Ablabesmyia dusoleili	0.82	89.58
Tanypus fuscus	0.82	90.39

K- Dominance curves

The K-dominance curves for the species at the 6 sampling sites (Figure 4) indicate the existence of several insect communities at the sites.

These curves show similar patterns. The species dominance curves of the Natiokobadara dam lake sites (Natiokobadara 1, Natiokobadara 2 and Natiokobadara 3) as well as that of Koko 2 are almost identical and are above the two species dominance curves of the other two sites (Koko 1 and Koko 3). The arrangement of these 4 curves shows that these 4 sites have the highest dominance and the lowest diversity. Conversely, the Koko 3 site has the lowest dominance and the highest diversity.

The curves for these 4 sites are higher than the curves for the others sites for all values of k. Thus, the assemblage in Natiokobadara 1, Natiokobadara 2 and Natiokobadara 3 and Koko 2 sites is unambiguously less diverse than that of Koko 1 and Koko 3 [29].

Aquatic insects distribution

Thirty-seven taxa are responsible for the differences between the Natiokobadara and Koko sites. The distribution of some of these taxa considered as the main taxa according to the importance of their abundance within the stand was carried out using correspondance analysis. The results of this analysis indicate that the abundance of the taxa *Anisops sardea* and *Diplonychus* sp. was high at Koko 2 (Figure 5). *Anisops* sp. was very abundant at Koko 1. The abundance of *Eurymetra* sp. appears to be high at Koko 3. *Pseudagrion massaicum*, *Chironomus imicola* and *Micronecta* sp. were abundant at Natiokobadara 3. As for *Ranatra linearis*, it was abundant at Natiokobadara 2. The abundance of *Anisops sardea* has been observed in previous work [30]. Indeed some genera of Heteroptera, such as *Anisops* have a global distribution and are frequently present in stagnant freshwater systems [31]. According to Dejoux *et al.* [13], *A. sardea* is a taxon that pulls preferentially in stagnant water.

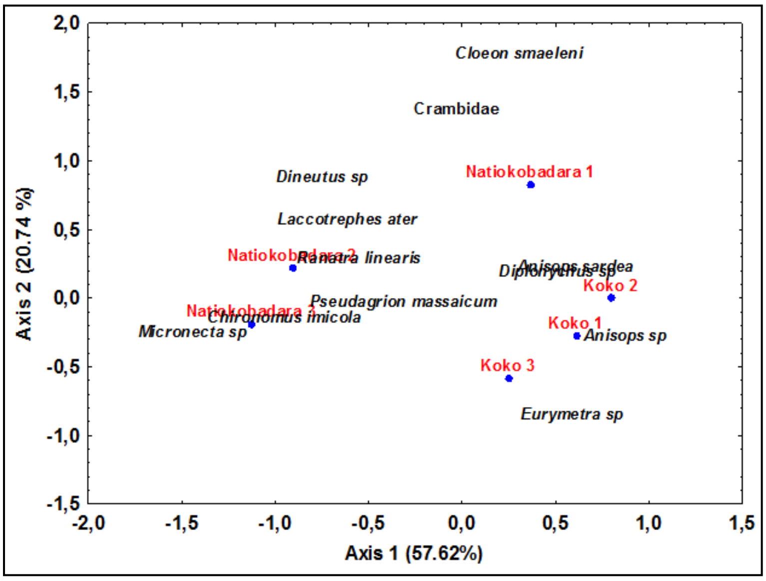

Fig 5: Correspondence analysis showing the distribution of the main taxa responsible for asymmetry within Koko and Natiokobadara dam lakes.

Conclusion

This study showed that dam lakes are suitable for diversified insects. According to species richness, Natiokobadara lake is home for more species of aquatic insects than Koko lake. The value of the Shannon-Wiener index and the Evenness were higher in Koko lake than in Natiokobadara lake. However, with regard to the similarity analysis, the insects richness was quite different in the two water bodies. The study of wildlife in aquatic water bodies could be useful in assessing the quality of these water bodies.

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