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Benthic macroinvertebrates ecology: distribution and niche shift in Sahelian reservoir in Burkina Faso

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Abstract

The ongoing human pressures from activities, linked to high population growth and the effects of climate change are the main threats to the world's aquatic ecosystems, particularly those of tropical freshwater. For instance, there is an urgent need of holistic approaches for suitable management of these vulnerable ecosystems for preserving aquatic biodiversity and ecosystems services. For that, the good knowledge of aquatic ecosystems functioning is required. As, macroinvertebrates are main organisms playing key role in aquatic ecosystems functioning, we have investigated on macroinvertebrates niche selection in reservoirs in Burkina Faso. To do so, macroinvertebrates were sampled monthly with a hand net following a multi-habitat sampling approach from June to December 2016, and Key physico-chemical variables were recorded. The preference range for physico-chemical variables was established at family level. A total of 30 families of macroinvertebrates were recorded revealing that the reservoir bears high taxa richness. Also, the results highlighted the change of macroinvertebrates community structure between months, and within the range of the physico-chemical factors. This shift of macroinvertebrates taxa due to the influences of physical and chemical factors heterogeneity is caused mainly by human disturbances that lowering water quality. Thus, the sensitive taxa, such as Ephemeroptera and Trichoptera decreased with decreasing dissolved oxygen concentration. For a better conservation of aquatic ecosystems and their biodiversity, it is necessary to avoid or mitigate human pressures on lakes ecosystems in Sahelian area.

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Introduction

Freshwater ecosystems provide valuable services for both nature and society (James *et al.*, 2021). But, the ongoing human pressures and the effects of climate change constitute the main threats to the world's aquatic ecosystems, particularly those in tropical freshwaters (Boyero and Bailey, 2001; Dudgeon *et al.*, 2006; Kaboré *et al.*, 2018). Indeed, they are the final receptacle of pollutants from all sources both humans and industrial (Kaboré *et al.*, 2018). As a result, the survival of aquatic organisms is compromised (Allan and Castillo, 2007) as well as the ecosystem services that benefit the local populations.

To preserve aquatic biodiversity and ecosystem services, it is urgent to find new approaches for suitable management of these ecosystems, which are listed among the most vulnerable. Thus, this requires a good knowledge of aquatic ecosystems functioning including human the pressures on these ecosystems. For this reason, more investigations on the abiotic and biotic characteristics of its environments and the interactions between these two factors (e.g. animals and water variables) are essential for better understanding of lakes functioning. Indeed, the spatial and temporal variation of fauna in hydro-systems depends on abiotic characteristics. These abiotic components and behavior have a greatest influence on macroinvertebrates communities, which have a very limited mobility and play an important role in whole ecosystems functioning, such as decomposers and of organic matter recycling, and also play an important role in food web (Odume *et al.*, 2016; Edegbene *et al.*, 2019). The availability of good habitats is the basic criteria for the survival of biodiversity and species distribution. Habitat preference and niche selection differ between taxa and between species (Heino and Tolonen, 2018; Porst *et al.*, 2019). Habitat heterogeneity in water bodies has a positive effect on macroinvertebrate diversity, and there is often a positive correlation between habitat diversity and macroinvertebrate species richness (Barbour *et al.*, 1999; Beisel *et al.*, 2000; Kaboré *et al.*, 2016a), because habitat diversity can provide not only a greater number of niches, but also a greater number of shelters in the event of disturbance and/or predation (Murdoch *et al.*, 1996; Kaboré *et al.*, 2016b). Studying the taxonomic composition and ecology of macroinvertebrates may help us to understand the mechanisms explaining the presence or absence of taxa or species, and also to predict the evolution of macroinvertebrates assemblage. This prediction is amongst the priority of scientific research in sub-Saharan zone where the preservation of the good ecological status of fresh waters and the restoration of degraded aquatic ecosystems are now in center policy maker's actions (Kaboré *et al.*, 2018; 2022).

Over the world, many studies have established relationships between benthic macroinvertebrates and environmental characteristics by using predictions curves and other statistics (Cotta-ramusino *et al.*, 1991; Jowett *et al.*, 1991; Bae *et al.*, 2020).

In sub-Saharan Africa, many studies on macroinvertebrates, among others, are focused on diversity, ecology, and their use as bioindicators (Adandedjan *et al.*, 2011; Camara *et al.*, 2012; Edia *et al.*, 2013; Dion *et al.*, 2019; Tampo *et al.*, 2020; Tanon *et al.*, 2020; Kaboré *et al.*, 2022a; b).

Also, in Burkina Faso, the diversity of macroinvertebrate and their relationship with environmental parameters have been undertaken (Guenda, 1996; Kabré *et al.*, 2000; 2002; Sanogo *et al.*, 2014; 2021; Kaboré *et al.*, 2016a; b; c; Bancé *et al.*, 2021a; b). But, the shift of macroinvertebrates communities for optimal physico-chemical factors condition is still very poorly documented. This study aimed to examine the shift of macroinvertebrate taxa along the key physico-chemical factors in reservoir.

Materials and methods

Study area

Burkina Faso is a Sahelian country drained by fourth national large river basins including Mouhoun, Nakanbé, Niger and Comoé, which have to cope with drought and water scarcity (Kaboré *et al.*, 2016a).

For this reason, s more than 1,500 reservoirs were built, and which constitute the main stocking water. The study was undertaken in the Ziga reservoir (Fig. 1), one of the largest stocking water in Burkina Faso with an area of 8,872.5 ha and a volume of 208 million m^3 during flooding. It is located between longitude 0°49'W and latitude 12°37'N, in the middle section of river Nakanbé. The Ziga reservoir was built in 1998 to supply drinking water to the local population and, Ouagadougou, capital of Burkina Faso. But this reservoir is under intense human pressures that lower its water quality (Melcher *et al.*, 2012). The Ziga reservoir's never dry out, and constitutes an important shelter for many aquatic organisms because of habitat heterogeneity, and it's accessible all the year.

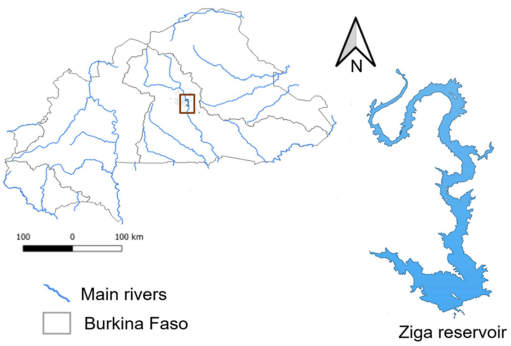


Fig. 1. Map of Burkina Faso showing the hydrographic and Ziga reservoir

Physico-chemicals variables measurement

The micro-habitats were characterized according to Moog (2007)**.** In each micro-habitat the following keys physicochemical variables: temperature, pH, electrical conductivity, dissolved oxygen was measured *in-situ* between 9 and 11 am using a calibrated portable multi-parameter device (*Hanna Instrument, HI9829*). The transparency was also measured using a Secchi disk. The measurements were carried out monthly from July to December 2016. Macroinvertebrates were collected immediately after the measurement of physicochemical variables.

Macroinvertebrates sampling

Benthic macroinvertebrates were sampled monthly in the micro-habitats encountered. Sampling was carried out with a hand net (aperture: 25cm×25cm; mesh size: 500µm), following the multi-habitat sampling method adapted from Barbour *et al.* (1999) and described in Kaboré *et al.* (2016a). Samples of each micro-habitat were preserved in alcohol (70%) and transported to the laboratory. Prior to sorting out the organisms, samples were sieved and the animals were sorted with the naked eye and under to a microscope. Finally, specimens were identified and enumerated using identification keys and manuals (Durand and Lévêque, 1981; Tachet *et al.*, 2010).

Data analysis

For environmental variables, descriptive statistics that include range, mean, and standard deviation for each environmental variable were calculated. Biodiversity indices including taxonomic richness, the Shannon diversity index and the Pielou equitability were used to highlight the structure of macroinvertebrate community.

Available habitat conditions were quantified using histograms, and their effects on relative abundance of taxa were visualized by a combination of line plots and histograms. To analyze the shift of macroinvertebrates taxa along the gradients of physicochemical variables, we established curves normalized probability density function ranging from 0 to 1 (Melcher and Schmutz, 2010) by using frequencies (Raleigh *et al.*, 1982) following eq. 1.

$$FUGi = \frac{fi}{f[max]} \quad 1$$

Where fi is class frequency and f [max] is maximum class frequency.

To check whether the physico-chemical variables vary significantly between the sampling months, a Kruskal-wallis test was performed ($p < 0.05$).

Results

Physico-chemical characterization of habitats

Table 1 shows the general trends of physicochemical variables. The water in reservoir is almost neutral, with a monthly average of pH ranging from 6.25 obtained to 7.08. The temperature is slightly high, characteristic of sub-Saharan aquatic ecosystems. It varied on average between 22.55°C in December and 28.9°C in September.

The lowest monthly average value of electrical conductivity was 50.56 µS/cm recorded in August and the highest was 152.14 µS/cm recorded in October. In overall, the water is poorly mineralized. Concerning dissolved oxygen, the reservoir is globally well oxygenated. The lowest average value is 4.53mg/l and the highest is 6.7mg/l, the Kruskall-Wallis test showed that the physico-chemical variables vary significantly between months ($p<0,05$), except temperature.

Benthic macroinvertebrates composition

A total of 3789 specimens of benthic macroinvertebrates were collected. They belong to 30 families, 12 Orders and 4 Classes (Table 2). The insects are the most abundant class with 3343 specimens (88.22% of total abundance) and the most diversified (24 families representing 72.72% of the total richness).

Table 1. General mean ± standard deviation of physico-chemical variables

	Mean and standard deviation per month			
	pH	Temperature	Electric conductivity	Dissolved Oxygen
July	6.76 ± 0.40	28.19 ± 3.19	113.50 ± 82.29	5.01 ± 0.07
August	7.08 ± 0.33	28.56±0.76	50.56±2.48	6.70±1.29
September	6.68 ± 0.03	28.9 ± 2.71	61.75 ± 14.91	6.41 ± 0.13
October	6.96 ± 0.51	27.82 ± 2.11	152.14 ± 72.87	4.53 ± 1.45
November	6.39 ± 0.22	23.26 ± 3.18	143.1 ± 66.31	4.64 ± 1.86
December	6.27 ± 0.24	22.55 ± 2.59	145.66 ± 64.74	5.41 ± 0.61
Overall	6.67± 0.44	26.24±3.68	110.14± 64.49	5,62± 1.22
p-value (KW)	0.02	0.05	0.01	0.01

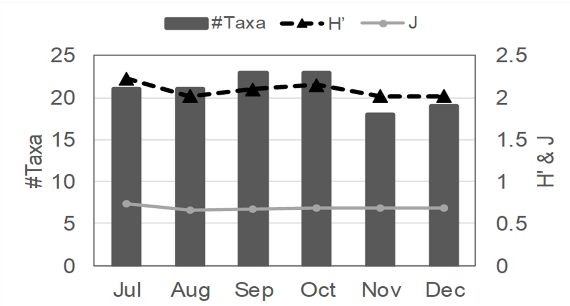
Table 2. List of taxa collected in Ziga reservoir

Class	Order	Family	Jul	Aug	Sep	Oct	Nov	Dec
Insect	Ephemeroptera	Baetidae		*	*	*	*	*
		Caenidae		*	*	*	*	*
		Leptoceridae		*				
		Oligoneuridae	*	*	*	*		
	Coleoptera	Dytiscidae				*	*	*
		Hydrophilidae	*	*	*	*	*	*
		Gyrinidae	*		*	*	*	
	Hemiptera	Belostomatidae	*	*	*	*	*	*
		Gerridae		*	*			
		Corixidae	*	*	*	*	*	*
		Velidae	*	*	*	*	*	*
		Notonectidae	*			*	*	*
		Nepidae				*	*	*
	Diptera	Chaoboridae	*		*	*		
		Chironomidae	*	*	*	*	*	*
		Culicidae			*	*		
		Ceratopogonidae	*		*			*
		Psychodidae	*		*			
		Simuliidae	*	*	*			
		Tabanidae	*	*	*	*	*	*
	Odonata	Libelliludae	*	*	*	*	*	*
		Aeshnidae	*	*	*			
		Coenagrionidae	*	*	*	*	*	*
		Gomphidae	*		*	*	*	*
	Trichoptera	Hydropsychidae			*	*		
Crustacea	Decapoda	Gecarcinucidae	*	*		*	*	*
		Palaemonidae						*
Clitellata	Arhynchobdellida	Hirudinae	*	*		*		*
Gastropoda	Mesogastropoda	Viviparidae	*	*				*
		Ampullaridae	*	*	*	*	*	*
		Bulinidae	*		*	*	*	
	Basommatophora	Planorbidae		*				
Bivalvia	Unionida	Iridinidae		*				

Jul=July; Aug=August; Sep=September; Oct= October; Nov=November; Dec=December

Temporal dynamic of population density and diversity indices of macroinvertebrates

The highest abundance was recorded in December and the lowest in July. Fig. 2 shows the variation in macroinvertebrate diversity during the sampling months. The Ziga reservoir bears high macroinvertebrates diversity, relatively, with the greatest taxonomic richness recorded in September and October. The Shannon and Pielou equitability indices were highest in July.



Jul=July; Aug=August; Sep=September; Oct= October; Nov=November; Dec=December

Fig. 2. Macroinvertebrates diversity indices

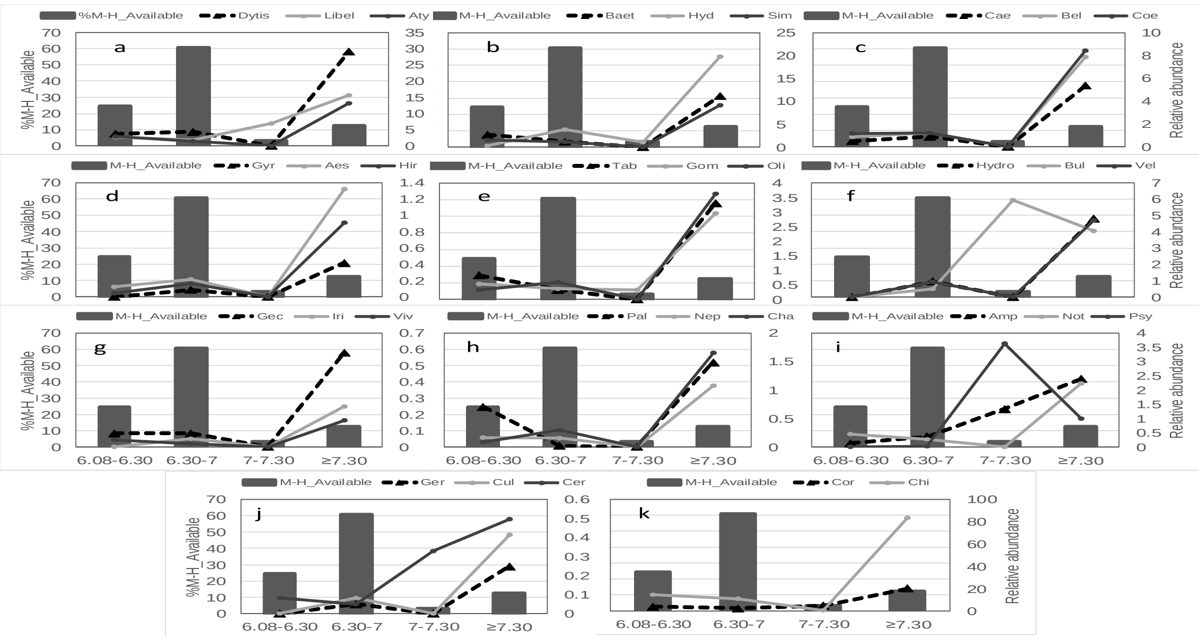


Fig. 2. pH niche selection curve for macroinvertebrates taxa

a (Dyt=Dytiscidae; Lib=Libellulidae; Aty=Atyidae) ; b (Bae=Baetidae ; Hyd=Hydrophilidae; Sim=Simulidae); c (Cae=Caenidae; Bel=Belostomatidae; Coe=Coenagrionidae); d (Gyr=Gyridinae ; Aes= Aeshnidae; Hir=Hirudinae); e (Tab= Tabanidae; Gom= Gomphidae; Oli= Oligochaeta); f (Hydrosp= Hydropsychidae ; Bul= Bulinidae ; Vel=Velidae); g (Gecarcinucidae; Iridinae; Viviparidae); h (Paleamonidae; Nep=Nepidae; Cha=Chaoboridae); i (Ampullaridae; Not=Notonectidae; Psy=Psychodidae); j (Ger=Geridae; Cul=Culicidae; Cer=Ceratopogonidae); k (Cor=Corixidae; Chi=Chironomidae)

Macroinvertebrates niche shift in reservoir

pH influence on niche selection

Three groups of macroinvertebrates can be distinguished on the basis of the pH ecological niche selection curve. The first group: Corixidae, Libellulidae, Ampullaridae and Ceratopogonidae, those abundance increases with increasing pH. The second group, made up of Psychodidae and Bulinidae, with maximum abundance at a pH range from 7 to 7.30 (Fig. 3). The third group, made up of Hydropsychidae, Oligoneuridae, Paleamonidae, Viviparidae, Iridinae, Amphipodidae, Chironomidae, Chaoboridae, Culicidae, Simuliidae, Tabanidae, Coenagrionidae, Aeshnidae, Gomphidae and Gecarcinucidae thoses with no clear trend, but their abundances are high for pH values above 7.30.

Temperature influence on niche selection

With the temperature four groups of macroinvertebrates are identified (Fig. 4). The first group including Culicidae, Gecarcinucidae, Atyidae, Hydropsychidae, Iridinidae, Oligoneuridae, Gyridinae, Simulidae and Aeshnidae that prefer temperatures range from 25 to 27°C.

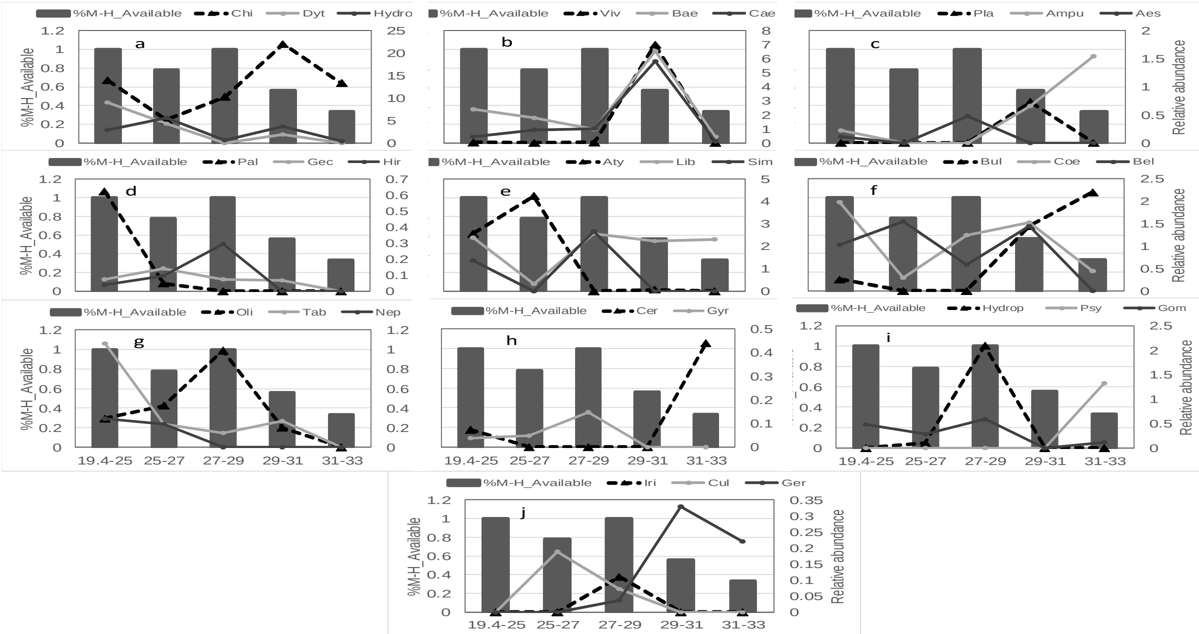


Fig. 4. Temperature niche selection curve for macroinvertebrates taxa encountered

a (Chi= Chironomidae; Dyt= Dytiscidae; Hydro= Hydrophilidae); b (Viv= Viviparidae; Bae= Baetidae; Cae= Caenidae); c (Pla=Planorbidae; Ampu= Ampularidae; Aes= Aeshnidae); d (Pal= Paleamonidae; Gec= Gecarcinucidae; Hir= Hirudinae); e (Aty=Atyidae; Lib=Libellulmidae; Sim=Simulidae); f (Bul=Bulinidae; Coe=Coenagrionidae; Bel=Belostomatidae); g (Oli=Oligoneuridae; Tab=Tabanidae; Nep=Nepidae); h (Cer= Ceratopogonidae; Gyr=Gyridinae); I (Hydrop=Hydropsychidae; Psy=Psychodidae ; Gom= Gomphidae); j (Iridinae; Cul=Culicidae; Ger=Geridae)

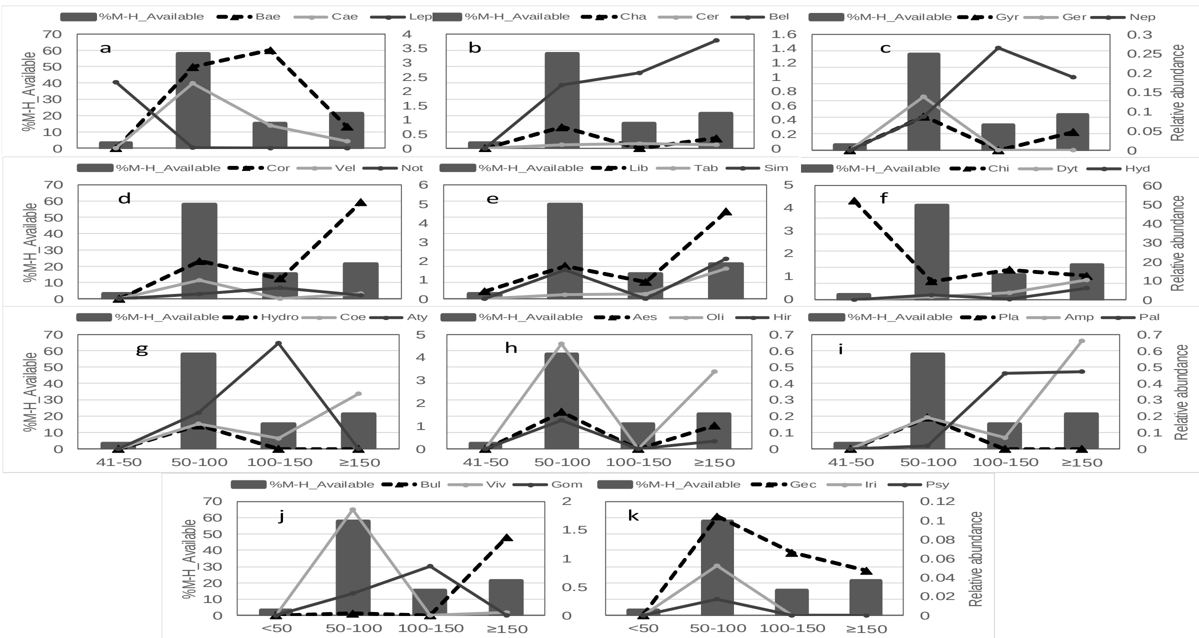


Fig. 5. Electrical conductivity niche selection curve for macroinvertebrates taxa encountered

a (Bae=Baetidae ; Cae=Caenidae ; Lept=Leptophlebeidae); b (Cha=Chaoboridae; Cer=Ceratopogonidae; Bel=Belostomatidae); c (Gyr=Gyrinidae ; Ger=Geridae ; Nep= Nepidae); d (Cor=Corixidae; Vel=Velidae; Not=Notonectidae); e (Lib=Libellulidae; Tab=Tabanidae; Sim=Simulidae); f (Chi=Chironomidae ; Hydro= Hydropsychidae; Dyt= Dytiscidae); g (Hydro=Hydrospsychidae; Coe=Coenagrionidae; Aty=Atyidae); h (Aes=Aeshnidae; Oli=Oligoneuridae; Hir=Hirudinae); i (Pla=Planorbidae; Amp=Ampularidae; Pal= Paleamonidae); j (Bul=Bulinidae ; Viv=Viviparidae; Gom=Gomphidae); k (Gec=Gecarcinucidae; Iri=Iridinae; Psy=Psychodidae)

Then, second group of the taxa: Baetidae, Caenidae, Gerridae, Viviparidae and Planorbidae abundant in intemperatures range from 29 to 31°C. The third group, made up of Nepidae, Tabanidae and Palaemonidae that are dominant at temperatures below 25°C and decrease in abundances with increasing temperatures. The fourth group is Belostomatidae, Coenagrionidae, Libellulidae, Gomphidae and Chironomidae that do not show a clear temperatures ranges.

Conductivity influence on niche selection

On the basis of conductivity curve, three groups of macroinvertebrate taxa can distinguish. The first group, made up of Caenidae, Gecarcinucidae, Culicidae, Hydropsychidae, Planorbidae, Viviparidae, Iridinidae and Psychodidae that are abundant in conductivity ranges comprisedbetween 50 and 100 µS/cm. The second taxa group included Ceratopogonidae, Nepidae, Gomphidae, Baetidae, Notonectidae and Psychodidae living in electrical conductivity between 100 and 150 µS/cm, and third group with unclear electrical conductivity niche ranges selection (Fig. 5).

Dissolved oxygen influence on niche selection

The ecological niche curves for dissolved oxygen show three groups of macroinvertebrates (Fig. 6). The first group, made up of Dytiscidae, Hydrophilidae, Tabanidae, Coenagrionidae, Gyrinidae and Corixidae that survive in water low oxygen contents, with highest abundance in range between 2 and 3 mg/L, but decreases with increasing dissolved oxygen concentration. The second group, made up of Baetidae, Caenidae, Hydropsychidae and Palaemonidae are the main sensitive taxa reported in reservoir, and prefers good habitats condition with relatively high oxygen contents. Their relative abundance increase with dissolved oxygen concentration, above 6 mg/l, and the third taxa group including Chironomidae, Chaoboridae and Veliidae show a relative abundance that evolves in a sawtooth pattern.

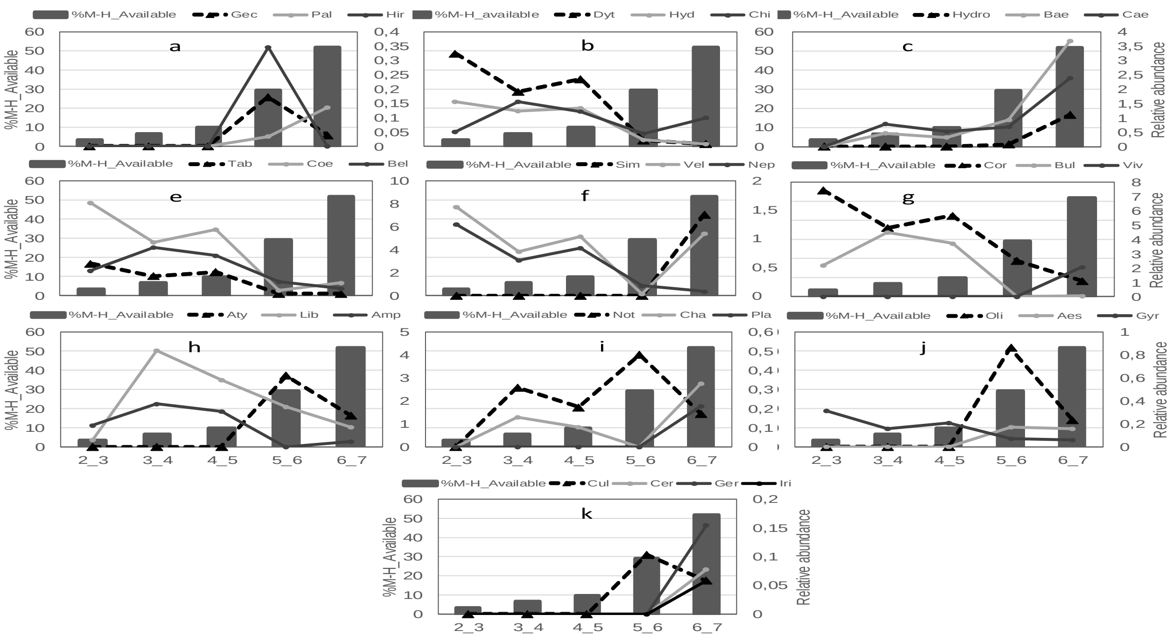


Fig. 6. Dissolved oxygen niche selection curve for macroinvertebrates taxa encountered a (Gec=Gecarcinucidae ; Pal=Paleamonidae ; Hir=Hirudinae); b (Hyd=Hydrophilidae; Bae=Baetidae; Cae=Caenidae); c (Dyt=Dytiscidae; Hydro=Hydropsychidae; Chi=Chironomidae); d (Tab= Tabanidae; Coe=Coenagrionidae; Bel=Belostomatidae); e (Sim=Simulidae; Vel=Velidae; Nep=Nepidae); f (Cor=Cordulidae; Bul=Bulinidae; Viv=Viviparidae); g (Aty=Atyidae; Lib=Libellulidae; Ampu=Ampularidae); h (Not=Notonectidae; Cha=Chaoboridae; Pla=Planorbidae); i (Oli=Oligoneuridae; Aes=Aeshnidae; Gyr=Gyrinidae); j (Cul=Culicidae; Cer=Ceratopogonidae; Ger=Gerridae ; Iri=Iridinae); k (Cul=Culicidae; Cer=Ceratopogonidae; Iri=Iridinae)

Discussion

A fundamental understanding of macroinvertebrate ecology is very important for planning and implementing strategies to manage aquatic ecosystems, and restore degraded habitats. Water physico-chemistry can be influenced by local physical disturbances, geologic of soils, edge use, and activities in watersheds. Any change in water chemistry can impact the structure of aquatic fauna (Pardo *et al.*, 2012; Arimoro *et al.*, 2015). pH is an important factor that determines the suitability of water for macroinvertebrates survival (Ahipathy and Puttaiah, 2006; Tampo *et al.*, 2021). For most natural fresh waters, the accepted pH range is 6.0 to 8.5 pH, and provide adequate life condition for aquatic organisms including macroinvertebrates (Life, 2004). The high temperatures obtained are characteristic of aquatic ecosystems in tropical zones, but are still suitable for aquatic life. The low conductivity values and high dissolved oxygen concentration recorded suggest good water quality of reservoir during the study period. Although they varied significantly in general between months, the values of all the physico-chemical variables recorded were within ranges that support aquatic life, particularly macroinvertebrate. The results show that the ranges of niches obtained here, reflect habitat heterogeneity, optimum condition for the development of a wide diversity of macroinvertebrates (Arimoro and Keke, 2017). Several authors have pointed out that habitat diversity is synonymous of high faunal diversity, especially macroinvertebrates (Martínez-Sanz *et al.*, 2012; Tokeshi and Arakaki, 2012; ST. Pierre and Kovalenko, 2014; Kaboré *et al.*, 2016a). Within the range values of the physico-chemical variables factors, each taxon grows and reproduces in optimum niche condition (Kearney and Porter, 2009; Kléparski and Beaugrand, 2022). The results of this study show that the shift and the preference can be linked to interaction between taxa, and are crucial for ecosystems functioning including biodiversity enhancing (Layman *et al.*, 2007; Laini *et al.*, 2019). Indeed, the lower range of pH [6.30-7] encountered in reservoir is unlikely shelter by macroinvertebrates than those niche range [7.30-8]. Overall, with regard to pH preference most of the taxa are well adapted to alkaline environment, thus reflecting their abundances shifts. Temperature is one of the determining parameters of aquatic environments, because it influences the solubility of gases (e.g. oxygen) and pollutants, the toxicity of chemicals substances. On the other hand, the temperature may also controls nutrient cycles, organic matter degradation and primary production (Luo *et al.*, 2017). In general, higher temperatures promote microbial metabolic activity and photosynthesis, and affect the development and performance of biotic communities (Bonacina *et al.*, 2023). According to some authors (Wotton, 1995; Lessard and Hayes,2003), there is a strong positive relationship between temperature and insect communities feeding rates and metabolism. This could explain by the fact that in tropical area, macroinvertebrates are well diversified because they prefer warm waters: temperatures between 29 and 31°C reflecting our findings. As for electrical conductivity, taxa naturally have a preference for low mineralized habitats (electrical conductivity between 50 and 100). Our results confirm those of Tampo *et al.* (2020), Bancé *et al.* (2021a) and Kaboré *et al.* (2022), who showed that electrical conductivity is negatively correlated with macroinvertebrate diversity. In fact, high electrical conductivity often reflects stressed environment, as a consequence the increasing of oxygen demand for micro-organisms, which is particularly harmful to polluo-sensitive macroinvertebrates taxa.

Conclusion

Our study reveals that the reservoirs harbor a high diversity of macroinvertebrates, but dominated by insects. The complex environment finds here with a heterogeneous ecological niche favor the development of a wide diversity of macroinvertebrates. From our findings, taxa niches shift in tropical reservoir may help to better conservation of biodiversity, environmental protection and degraded habitats restorations.

Acknowledgments

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Declaration of interests

The authors have no conflicts of interest to declare.

References

Adandédja D, Lalèyè P, Gourène G. 2012. Macroinvertebrates communities of a coastal lagoon in southern Benin, West Africa. International Journal of Biological and Chemical Sciences **6**(3), 1233-1252;

Allan JD, Castillo MM. 2007. Stream ecology: structure and function of running waters. 2. Ed., Springer, Dordrecht;

Ahipathy MV, Puttaiah ET. 2006. Ecological characteristics of vrishabhavathy River in Bangalore (India). Environmental Geology **49**(8), 1217-1222.

Arimoro FO, Odum, ON, Uhunoma SI, Edegbene AO. 2015. Anthropogenic impact on water chemistry and benthic macroinvertebrate associated changes in a southern Nigeria stream. Environmental Monitoring and Assessment **187**, 1-14.

Arimoro FO, Keke UN. 2017. The intensity of human-induced impacts on the distribution and diversity of macroinvertebrates and water quality of Gbako River, North Central, Nigeria. Energy, Ecology and Environment **2**, 143-154.

Bae MJ, Park SM, Kim JK, Hong JG, Ryu SH. 2020. The Relationships between Benthic Macroinvertebrate and Environmental Factors in Iancheon and Bukcheon Streams, Korea. *Korean* Journal of Ecology and Environment **53**(1), 22-30.

Bancé V, Ouéda A, Kaboré I, Zerbo H, Kabré BG. 2021a. Ecological status of a newly impounded sub-Saharan reservoir based on benthic macroinvertebrates community (Burkina Faso, West Africa). Journal of Ecology and The Natural Environment **13**(1), 1-13.

Bancé V, Ouéda A, Kaboré I, Ouédraogo I, Mano K, Weesie PDM, Kabré BG. 2021b. Influence of micro-habitats on the distribution of macroinvertebrates in the Ziga Reservoir, Burkina Faso, West Africa. Int. J. Aquat. Biol. **13**, 177-186.

Barbour MT, Gerritsen J, Snyder BD, Stribling JB. 1999. Rapid Bio Assessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish, Second Edition. EPA 841-B-99-002. U.S. Environmental Protection Agency, Office of Water; Washington, D.C.

Beisel JN, Usseglio-Polatera P, Moreteau JC. 2000. The spatial heterogeneity of a river bottom : a key factor determining macroinvertebrate communities. In Assessing the Ecological Integrity of Running Waters: Proceedings of the International Conference, held in Vienna, Austria, 9–11 November 1998 (pp. 163-171). Springer Netherlands.

Bonacina L, Fasano F, Mezzanotte V, Fornaroli R. 2023. Effects of water temperature on freshwater macroinvertebrates: a systematic review. Biological Reviews **98**(1), 191-221.

Boyero L., Bailey RC. 2001. Organization of macroinvertebrate communities at a hierarchy of spatial scales in a tropical stream. Hydrobiologia **464**, 219-225.

Camara IA, Diomande D, Bony YK, Ouattara A, Franquet E, Gourene G. 2012. Diversity assessment of benthic macroinvertebrate communities in B anco N ational P ark (Banco Stream, Côte d'Ivoire). African Journal of Ecology **50**(2), 205-217.

Cotta-Ramusino M, Crosa G, Buffagni A. 1991 Microhabitat preferences of benthic fauna (Ephemeroptera) in plane-springs (fontanili), Internationale Vereinigung für theoretische und angewandte Limnologie: Verhandlungen, 24:3, 1626-1628, DOI: 10.1080/03680770.1989.11899036

Dewson ZS, James AB, Death RG. 2007. A review of the consequences of decreased flow for instream habitat and macroinvertebrates. Journal of the North American Benthological Society **26**(3), 401-415.

Dion BR, Konan KJ, Yapo LM, Kouassi KP. 2019. Taxonomic diversity and structure of Macroinvertebrates in two small marginal lagoons of the South-eastern of Côte d'Ivoire. International Journal of Innovation and Applied Studies **26**(4), 992-1003.

Dudgeon D, Arthington AH, Gessner MO, Kawabata ZI, Knowler DJ, Lévêque C, Sullivan CA. 2006. Freshwater biodiversity: importance, threats, status and conservation challenges. Biological Reviews of the Cambridge Philosophical Society **81**, 163-182.

Durand JR, Lévêque C. 1981. Flore et faune aquatiques de l'Afrique sahélo-soudanienne (Tome II). Paris, France: *ORSTOM*. **483**p.

Edegbene AO, Arimoro FO, Odume ON. 2019. Developing and applying a macroinvertebrate-based multimetric index for urban rivers in the Niger Delta, Nigeria. Ecology and Evolution **9**(22), 12869-12885.

Edia OE, Bony KY, Konan KF, Ouattara A, Gourène G. 2013. Distribution of Aquatic Insects among Four Costal Rivers habitats (Côte d'Ivoire, West-Africa). Bulletin of Environment, Pharmacology and Life Sciences **2**(8), 68-77.

Guenda W. 1996. Etude faunistique, écologique et de la distribution des insectes d'un réseau hydrographique de l'Ouest africain : le Mouhoun (Burkina Faso) ; rapport avec Similium damnosum Theobald, vecteur de l'onchocercose. Thèse d'état, Univ. Aix Marseille. **260** p.

Heino J, Tolonen KT. 2018. Ecological niche features override biological traits and taxonomic relatedness as predictors of occupancy and abundance in lake littoral macroinvertebrates. Ecography **41**(12), 2092-2103.

James SA, Destouni G, Scott MDS, Anne EM, Thierry O, Roberto ER, Kirk OW, William JR. 2021. Scientists' warning to humanity on the freshwater biodiversity crisis. Ambio **50**, 85–94. https://doi.org/10.1007/s13280-020-01318-8

Jowett IG, Richardson J, Barry JFB, Christopher WH, John MQ. 1991. Microhabitat preferences of benthic invertebrates and the development of generalized Deleatidium spp. habitat suitability curves, applied to four New Zealand rivers, New Zealand Journal of Marine and Freshwater Research **25**(2), 187-199,
DOI: 10.1080/00288330.1991.9516470

Kaboré I, Moog O, Alp M, Guenda W, Koblinger T, Mano K, Ouéda A, Ouédraogo R, Trauner D, Melcher AH. 2016a. Using macroinvertebrates for ecosystem health assessment in semi-arid streams of Burkina Faso. Hydrobiologia **766** (1), 57-74.
DOI:http://dx.doi.org/10.1007/s10750-015-2443-6.

Kaboré I, Ouédraogo I, Tampo L, Ouéda A, Moog O, Guenda W, Melcher AH. 2016b. Diversity, composition and dynamic of benthic macroinvertebrate community in semiarid rivers of Burkina Faso (West Africa). International Journal of Biological and Chemical Sciences.

Kaboré I, Jäch MA, Ouéda A, Moog O, Guenda W, Melcher AH. 2016c. Dytiscidae, Noteridae and Hydrophilidae of semi-arid waterbodies in Burkina Faso: species inventory, diversity and ecological notes. Journal of Biodiversity and Environmental Sciences **8**(4), 1-14.

Kaboré I, Tampo L, Bancé V, Daboné C, Mano K, Ayoro HJ, Ouéda A. 2022. Preliminary biological data of Sahel wetland ecosystems in Burkina Faso: Implications for ecological health assessment. Frontiers in Conservation Science **3**, 913333.

Kaboré I, Ouéda A, Moog O, Meulenbroek P, Tampo L, Bancé V, Melcher AH. 2022. A benthic invertebrates-based biotic index to assess the ecological status of West African Sahel Rivers, Burkina Faso. Journal of Environnemental Management **307**, 114503.

Kabré TA, Diguingué D, Bouda S. 2002. Effet du rétrécissement de la superficie d'eau sur les macroinvertébrés du lac de barrage de la Comoé, Sudouest du Burkina Faso. Science et Technique, série Sciences Naturelles et Agronomie **26**(1), 37-49.

Kabré TA, Ille A et Guenda W. 2000. Inventaire et étude de la densité de distribution des insectes du benthos des deux lacs de barrage de Bagré. Science et technique, Sciences naturelle et agronomique, **24** (2), 121-132.

Kearney M, Porter W. 2009. Mechanistic niche modelling: combining physiological and spatial data to predict species' ranges. Ecology letters **12**(4), 334-350.

Kléparski L, Beaugrand G. 2022. The species chromatogram, a new graphical method to represent, characterize, and compare the ecological niches of different species. Ecology and Evolution **12**(4), e8830.

Laini A, Viaroli P, Bolpagni R, Cancellario T, Racchetti E, Guareschi S. 2019. Taxonomic and functional responses of benthic macroinvertebrate communities to hydrological and water quality variations in a heavily regulated river. Water **11**(7), 1478.

Layman CA, Quattrochi JP, Peyer CM, Allgeier JE. 2007. Niche width collapse in a resilient top predator following ecosystem fragmentation. Ecology letters **10**(10), 937-944.

Lessard JL, Hayes DB. 2003. Effects of elevated water temperature on fish and macroinvertebrate communities below small dams. River research and applications **19**(7), 721-732.

LIFE FA. 2004. pH requirements of freshwater aquatic life.

Luo L, Meng H, Gu JD. 2017. Microbial extracellular enzymes in biogeochemical cycling of ecosystems. Journal of Environmental Management **197**, 539-549.

Martínez-Sanz C, Cenzano CS, Fernández-Aláez M, García-Criado F. 2012. Relative contribution of small mountain ponds to regional richness of littoral macroinvertebrates and the implications for conservation. *Aquatic Conservation: Marine and* Freshwater Ecosystems **22**(2), 155-164.

Melcher AH, Schmutz S. 2010. The importance of structural features for spawning habitat of nase *Chondrostoma nasus* (L.) and Barbel *Barbus barbus* (L.) in a pre-alpine river. River Syst. **19**, 33–42.

Melcher AH, Ouedraogo R, Schmutz S. 2012. Spatial and seasonal fish community patterns in impacted and protected semi-arid rivers of Burkina Faso. Ecological Engineering **48**, 117-129;

Moog O. 2007. Deliverable 8 – Part 1. Manual on Pro-rata Multihabitat-sampling of Benthic Invertebrates from Wadeable Rivers in the HKH-Region. BOKU – University of Natural Resources and Applied Life Sciences, Vienna. P28 www.assess-hkh.at.

Murdoch WW, Warbrick SL, Luck SRF, Walde S, YUD S. 1996. Refuge dynamics and meta-population dynamics: an experimental test.

Odume ON, Palmer CG, Arimoro FO, Mensah PK. 2016. Chironomid assemblage structure and morphological response to pollution in an effluent-impacted river, Eastern Cape, South Africa. Ecological Indicators **67**, 391-402.

Pardo I, Gómez-Rodríguez C, Wasson JG, Owen R, van de Bund W, Kelly M, Bennett C, Birk Sf, Buffagni Ag, Erba S, Mengin N, Murray-Bligh J, Ofenböeck G. 2012. The European reference condition concept: a scientific and technical approach to identify minimally-impacted river ecosystems. Science of the Total Environment **420**, 33-42.

Porst G, Brauns M, Irvine K, Solimini A, Sandin L, Pusch M, Miler O. 2019. Effects of shoreline alteration and habitat heterogeneity on macroinvertebrate community composition across European lakes. Ecological Indicators **98**, 285-296.

Sanogo S, Kabre TJ. 2014. Dynamique de structuration spatio-temporelle des populations de familles de macroinvertébrés dans un continuum lac de barrage-effluent-fleuve issu de périmètre irrigué. Bassin de la Volta (Burkina Faso). Journal of Applied Biosciences **78**, 6630-6645.

Sanogo S, Compaore I, Sawadogo B, Ouedraogo RB, Zongo B, Nacro HB. 2020. Effect of anthropization on macroinvertebrate communities in the Kou River, Burkina Faso. International Journal of Environment, Agriculture and Biotechnology **5**(6). https://dx.doi.org/10.22161/ijeab.56.27

St. Pierre JI, Kovalenko KE. 2014. Effect of habitat complexity attributes on species richness. Ecosphere **5(2)**, 1-10.

Tachet H, Richoux P, Bournaud M, Usseglio-Polatera P. 2010. Invertébrés d'eau douce Systématique, biologie, écologie. CNRS éditions, Paris, **587** p,

Tampo L, Lazar MI, Kaboré I, Ouéda A, Akpataku KV, Djaneye-Boundjou G, Bawa LM, Lazar G, Guenda W. 2020. A multimetric index for assessment of aquatic ecosystem health based on macroinvertebrates for the Zio river basin in Togo. Limnologica **83**, 125783.

Tanon YD, Camara IA, Kouadio NK, Doumbia L, Ouattara A, Diomandé D. 2020. Taxonomic diversity and structure of benthic macroinvertebrates of Taabo Lake (Basin of Bandama; Ivory Coast). Journal of Environmental Science Studies **3**(1), 1.

Wotton RS. 1995. Temperature and lake-outlet communities. Journal of Thermal Biology **20**(1-2), 121-125.